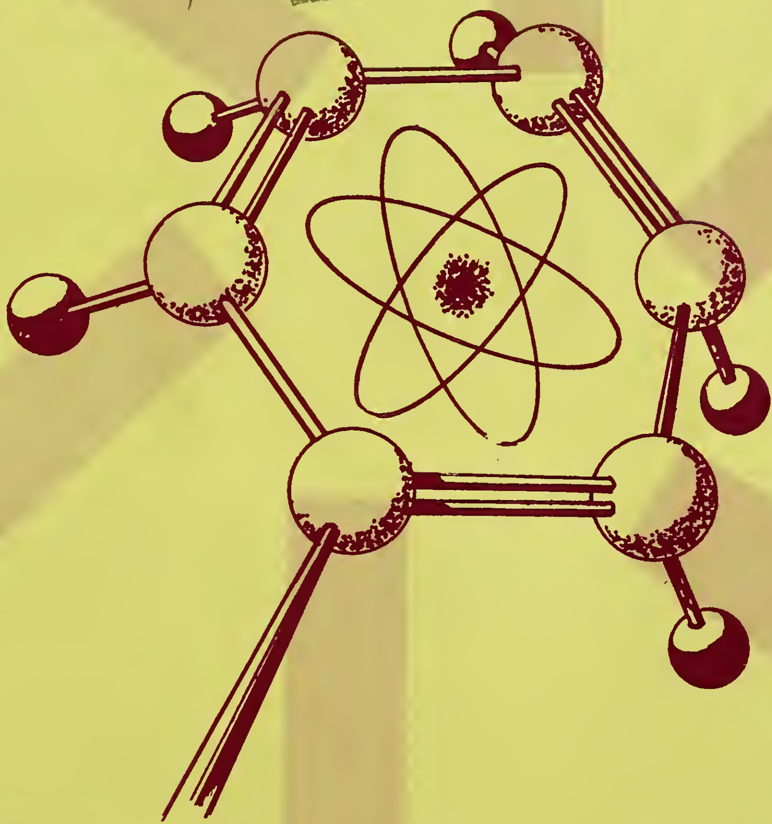
USDA RADIOLOGICAL TRAINING MANUAL



U.S. DEPARTMENT OF AGRICULTURE
AGRICULTURAL RESEARCH SERVICE

FOREWORD

Annex 23 (National Radiological Defense Plan) to the National Plan for Civil Defense and Defense Mobilization states that "Monitoring systems will be developed at all levels of government to detect and evaluate the hazards resulting from an attack . . . state and local systems will provide detailed monitoring services for operational use." The annex further states "The Department of Agriculture shall prepare national emergency plans and develop preparedness programs for radiological defense as it affects livestock, crops, meat and poultry, and agriculture generally."

In carrying out this delegation, the Department of Agriculture must develop and maintain a knowledge and capability within its field forces for monitoring and providing technical guidance to agricultural officials, farmers, and Forest Service personnel on protection against, and remedial measures to be taken to minimize, the radiation hazards on agricultural resources and food products therefrom. The Department has also been requested by the Office of Civil and Defense Mobilization (OCDM) to provide trained personnel to man and operate those Federal fixed monitoring stations located throughout the United States assigned to the USDA by OCDM.

Secretary's Memorandum No. 1430 assigns responsibility for radiological monitoring to several Department agencies having field organizations and established field programs. These areas of responsibility include (a) agricultural lands, including forest lands; (b) water used for agricultural purposes; (c) agricultural commodities stored or harvestable on farms and ranches; (d) livestock, including poultry; (e) meat and meat products and poultry and poultry products; and (f) agricultural commodities and products owned by CCC and USDA.

Department agencies with radiological defense responsibilities include the Agricultural Marketing Service, Agricultural Research Service, Forest Service, and Soil Conservation Service.

To provide the above capability, Department of Agriculture personnel must be trained in radiological monitoring. This manual has been prepared to assist in providing information and guidance to those who are responsible for conducting this emergency service within the Department.

Much of the material contained in this publication has been drawn from lectures prepared and given in training courses conducted by the staff of the Agricultural Research Service. Selected material from Congressional Hearings before the Special Subcommittee on Radiation of the Joint Committee on Atomic Energy is also included.

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PART I

THE COMPOSITION OF MATTER[1/]

The understanding of such terms as "atomic energy," "radiation," "ionization," and similar words is not an easy matter. In fact, the word "atom" itself has assumed a much greater importance in our lives during the past two decades than ever before. Yet to fully understand this new vocabulary and to be able to use it is almost a necessity, if we are to understand atomic energy and be able to meet the problems that the use of this form of energy will present to us in the future. Not only do we need this knowledge to meet any national emergency that might arise where atomic warfare could result, but there is also the possibility of accidents to power reactors which might produce significant problems. It is necessary that we have a basis for intelligent action concerning radiation in order to fulfill the function expected of us as professional, scientific, and technical personnel.

The term radiation means nothing more than "the release of radiant energy." Here we intend to study radiant energy and apply this study to agriculture and its many areas of production. But, as we have said, to understand radiation we must know the meaning of the terms used and how they explain radiation and its effects on food and ultimately the person consuming the food. A working knowledge can be obtained with study and explanation that will enable us to handle the great majority of questions we shall be called on to answer in our work.

Atoms

As a starting point let us consider the word "atom." What is an atom? The first man who tried to fathom the mystery of the smallest of naturally occurring particles was the Greek philosopher Democritus, who lived in Athens about 23 centuries ago. He believed that no matter how homogeneous matter appeared, it must be considered to be formed by a large number of separate small particles which he called "atoms" or "indivisibles." He didn't know the number of particles necessary to form any visible piece of matter or how small the particles might be, but he did believe that these atoms were different in various substances but were all alike in the same substance.

During the early part of the twentieth century this basic concept of the atom was enlarged upon and the science of atomic physics came into its own. Niels Bohr, a Danish physicist, assembled all the available data of physics and chemistry on atoms

1/ Prepared by James D. Lane, Meat Inspection Division, Agricultural Research Service, U. S. Department of Agriculture.

and their structure and presented his theory of the atom. The theory he proposed is accepted as the correct one today, and he was awarded the 1912 Nobel prize for his work. According to him, the atom really looks a great deal like our solar system. At the center is a massive, dense nucleus, corresponding to our sun. At a great distance away from the center are lighter particles, which spin around it in circular or elliptical orbits, just as the earth and other planets revolve around the sun. Just as most of the volume of the solar system is empty space, the atom, a miniature solar system, also is mostly empty space. Bohr said that the central mass was composed of a varying number of closely packed, positively charged heavy particles, called protons. The particles flying around the nucleus are much lighter and are negatively charged. These are called electrons.

According to Bohr, the properties of elements (92 occur on the earth) are completely determined by the number of protons and electrons contained in the atoms of the elements. As an example of the comparative size of the parts of an atom, if we assume that the nucleus were the size of a small pea, the electrons would be located about the length of a football field away. And the difference in weight between the parts of an atom is enormous; a proton is 1,840 times heavier than an electron. From this Bohr deduced that the weight (or mass, as it is called) of an atom is determined by the number of protons present. Thus, an atom of hydrogen, which has only one proton, is said to have a mass of one. The next atom, that of helium, has a mass of four (four times heavier than an atom of hydrogen), but it has only two protons. The rest of the mass subsequently was found to come from the presence of two additional fundamental particles. And these are called neutrons.

A neutron may be described as a proton without a charge, or a proton combined with an electron. Thus the neutron has no charge, but its mass is nearly the same as that of the proton, since the electron contributes only a very small amount of the mass. Sometimes we speak of protons and neutrons under the common name of nucleons, since they are both found in the nucleus.

So we now see that the atoms of the various chemical elements consist of a heavy nucleus composed of positively charged protons and uncharged neutrons surrounded by very light, negatively charged electrons. In a stable element the number of protons and electrons are always the same so that the total number of positive (proton) charges equals the number of negative (electron) charges and the atom is electrically neutral. In an electrical field like charges always repel and unlike charges always attract, so it is easy to see how the attraction between the protons and electrons tends to stabilize the atom. (See Fig. 1 - Helium Atom.)

The difference between various chemical elements must be ascribed to the different number of electrons rotating around the nucleus. Since the atom as a whole is electrically neutral, the number of electrons rotating around its nucleus must be determined by the number of protons carried by the nucleus. In the natural sequence of chemical elements arranged in the order of increasing weights, there is a consistent increase of 1 atomic electron and 1 proton in each element in the sequence. Thus, an atom of hydrogen has 1 electron and 1 proton; an atom of helium, 2 electrons and 2 protons; lithium, 3 electrons and protons; beryllium, 4 each; and so on up to the heaviest natural element, uranium, which has 92 electrons and 92 protons.

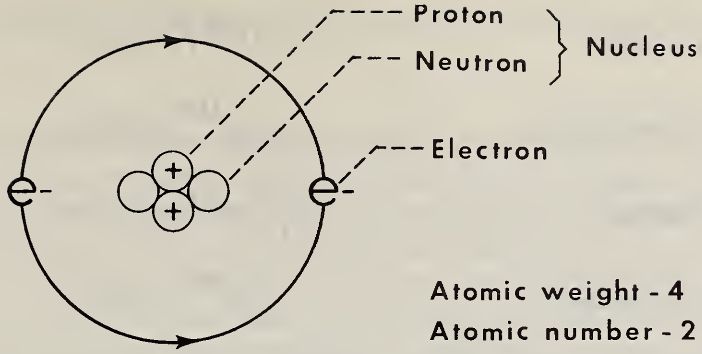

Figure 1.—Helium atom.

This numerical designation of an atom (and here we are speaking only of the number of protons in the nucleus) is usually known as the atomic number of the element in question. It is written to the lower left of the atomic symbol to indicate the number of protons in the element. This is written chemically as:

$_{8}0$ (Oxygen) $\quad$ $_{7}N$ (Nitrogen) $\quad$ $_{92}U$ (Uranium)

Another atomic symbol often used is atomic weight or mass number, meaning the total number of protons and neutrons in any particular element. This atomic weight is written to the upper right of the chemical symbol to show oxygen as $_{8}O^{16}$, nitrogen as $_{7}N^{14}$, etc., and indicates, for example, that an atom of oxygen contains 8 protons (atomic number) plus 8 neutrons, and has an atomic weight of 16. The material sometimes used to release atomic power is $_{92}U^{235}$, which indicates that it is uranium, contains 92 protons, and has an atomic weight of 235 (92 protons plus 143 neutrons).

The following form is generally used in writing any isotope of an element:

$$\text{(atomic number) } {}_{Z}X^{A} \text{ (mass number)}$$

Where: X = chemical symbol of element
A = mass number = number of protons + number of neutrons
Z = atomic number = number of protons = number of orbital electrons in the neutral atom

The following chemical symbols of some of the more common elements, the atomic number and atomic weight of each, give us a good idea of the atomic structure of atoms as they become heavier:

$_{1}H^{1}$ (Hydrogen) $\quad$ $_{7}N^{14}$ (Nitrogen)

$_{14}Si^{28}$ (Silicon) $\quad$ $_{26}Fe^{56}$ (Iron)

$_{2}He^{4}$ (Helium) $_{8}O^{16}$ (Oxygen)

$_{15}P^{31}$ (Phosphorus) $_{47}Ag^{108}$ (Silver)

$_{6}C^{12}$ (Carbon) $_{11}Na^{23}$ (Sodium)

$_{19}K^{39}$ (Potassium) $_{82}Pb^{207}$ (Lead)

The nuclei of various atoms do not always contain the same number of protons and neutrons. Quite the contrary, as the atomic weight of the elements increases the atomic number also goes higher, but it falls farther and farther behind the atomic weight, until in our very heaviest elements we may have almost twice as many neutrons as protons. Yet in our lighter elements the ratio of proton to neutron is about equal. In fission ''neutron heavy'' nuclei play an important role.

Bohr's model of the atom also showed that the electrons which circle the nucleus in an electron could adhere to a definite arrangement and the arrangement of these electrons determine the physical properties of the elements. The atoms of each element possess a definite number of orbits in which the electrons revolve, and these orbits are at fixed distances from the nucleus. The first completed shell must consist of 2 electrons, and the next of 8 electrons, the third shell contains a maximum of 18 electrons, but a stability is found when only 8 electrons are present. The fourth shell may contain a maximum of 32 electrons, but again a stability is evident when only 8 electrons are in this shell. When the outer orbit is filled, or it reaches a stable number, the element is inactive chemically. When these conditions are not met the element can react chemically. (See Fig. 2 - Oxygen Atom.)

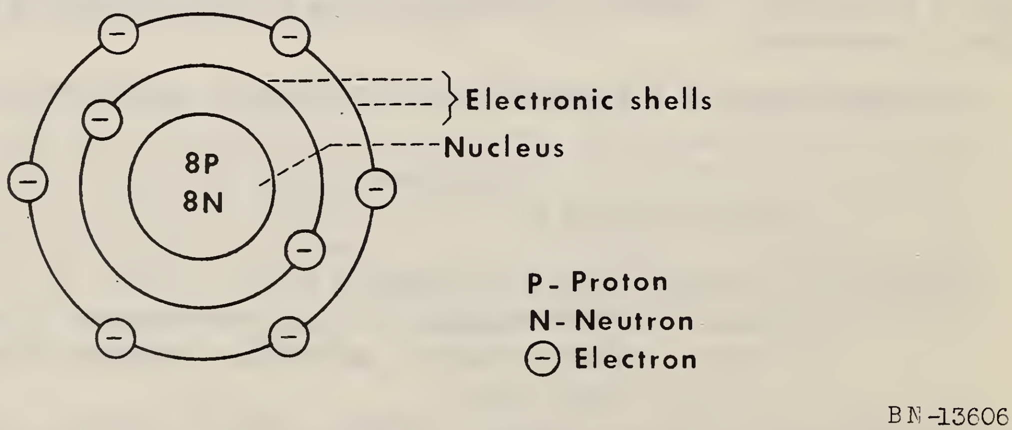

Figure 2.—Oxygen atom.

Isotopes

Now that we know the structure of an atom and how the electrical charges of the protons and electrons tend to keep the atom from flying apart, let us consider the

possibilities of slightly different types of atoms composing any one specific chemical element.

An element is defined in structure and in properties by its atomic number (total protons) and atomic weight (total protons and neutrons). Of the two, the atomic number is the most important, since it determines the chemical properties. This method of describing an atom had proven very satisfactory until some discrepancies were noted in the atomic weights of some of the free elements. Chlorine has an atomic number of 17 but the atomic weight of free chlorine was found to be 35.5. Since it is obviously impossible for the nucleus of chlorine to contain 18-1/2 neutrons, this presented a real problem for some time. It was not until the year 1919 that the discovery of the British physicist F. W. Aston showed that ordinary chlorine represents a mixture of two different kinds of chlorine possessing identical chemical properties but having different atomic weights and this resolved the mystery. He found that ordinary chlorine is a mixture of 3 parts of chlorine having an atomic weight of 35 and 1 part chlorine having an atomic weight of 37. Thus the value 35.5 is merely the mean between these two numbers.

Although all atoms of any one element must contain the same number of protons, they need not contain the same number of neutrons. Such atoms of any element, differing only in the number of neutrons in their nuclei, are known as isotopes. It has since been found that practically every element as found in nature is really a mixture of two or more isotopes. Ordinary hydrogen consists of three isotopic forms, all of which have an atomic number of one, but possess atomic weights of 1, 2, and 3. The isotope of atomic weight 1 is by far the most abundant, composing about 99.98% of the total hydrogen. The isotope of atomic weight 2 is known as deuterium or "heavy hydrogen," and occurs to the extent of only 0.02% of the total hydrogen. The third isotope, called tritium, is even less abundant than deuterium. Chemically these isotopes may be shown as ${}_1H^1$, ${}_1H^2$, and ${}_1H^3$. Remember that each of these isotopes contains only one proton with ${}_1H^1$ having no neutron, ${}_1H^2$ contains one neutron, and ${}_1H^3$ having two neutrons in its nucleus.

To demonstrate this further, silicon also has three naturally occurring isotopes. ${}_{14}Si^{28}$ composes 92% of free silicon, ${}_{14}Si^{29}$ composes 5%, and ${}_{14}Si^{30}$ composes the remaining 3%. Besides the many naturally occurring isotopes in nature (there may be from 1, as in the case of helium, to 10, as in the case of tin), there have been many artificially produced isotopes in recent years. This has been a direct result of our atomic age and up to 1,200 isotopes of the elements known to man have been recorded.

The important thing to remember is that all elements are composed of isotopes of that element. Although there may be only one naturally occurring isotope, as in the case of helium, yet other isotopes of helium have been produced, and each atom of that element, regardless of its abundance or scarcity in nature, is considered an isotope.

All matter can be classified into elements and compounds. The elements cannot be resolved into simpler types of matter by chemical means because the elements are composed of homogeneous atoms. And as the atom is the basic chemical particle, it cannot be further divided by chemical means. However, the compounds do not have this same quality. Such materials as water, table salt, and oil, although they too are homogeneous, can be divided by chemical means. The reason for this is that compounds are composed of two or more different elements which have combined to form a compound and can be divided by chemical means to separate the component atoms.

These bound atoms that form a compound, such as common salt, have chemical and physical properties which clearly differentiate them from any other compound or element. When this coumpound is subdivided into smaller and smaller pieces, eventually the point is reached where it can no longer be divided without completely changing its properties. This smallest part of the compound, which resists further subdivision without change of properties, is called a molecule. Thus the molecule is the smallest unit of a compound, but the molecule itself is composed of atoms of two or more different elements. (Molecules also can be solely composed of atoms of the same element.)

Figure 3 shows the relative binding energy per nucleon for the isotopes ranging from a low binding energy for hydrogen on the left of the scale to that of uranium-238 on the right of the scale. This indicates that the majority of the isotopes falling between the two extremes of hydrogen and uranium have nuclei that are relatively difficult to split. Krypton, as an example, in the center of the scale would be extremely difficult to fission; however, as we approach nearer to the right-hand edge of the scale the nuclei of the isotopes are held together more loosely. On the other hand, hydrogen with the lowest binding energy of all elements can be altered and caused to fuse with the proper amount of energy applied to the nucleus. The nuclei of hydrogen and the other lighter elements will not readily fission though because of the small size of the nucleus and the relatively few particles contained in the nucleus.

The atoms in any specific molecule are joined together in a definite ratio by weight or by number. For instance, a molecule of common salt is always composed of one atom of sodium bound to one atom of chlorine, and this molecule is designated chemically as NaCl. In like respect, a molecule of water is composed of two atoms of hydrogen bound to one atom of oxygen, and is designated as H_2O. To get into the more complex compounds, sulfuric acid is written as H_2SO_4, indicating 2 hydrogen atoms, 1 sulfur atom, and 4 oxygen atoms bound together. The important thing to remember is that every molecule of each specific compound is formed in exactly the same way with the same ratio of atom combinations.

Such compounds as proteins, carbohydrates, and some of our newer drugs have a very complex molecular structure composed of literally hundreds of atoms, whereas there are also many compounds composed of very simple molecules. And each type, as well as all varying shades of complexity between the two, can be found in the bodies of animals and man.

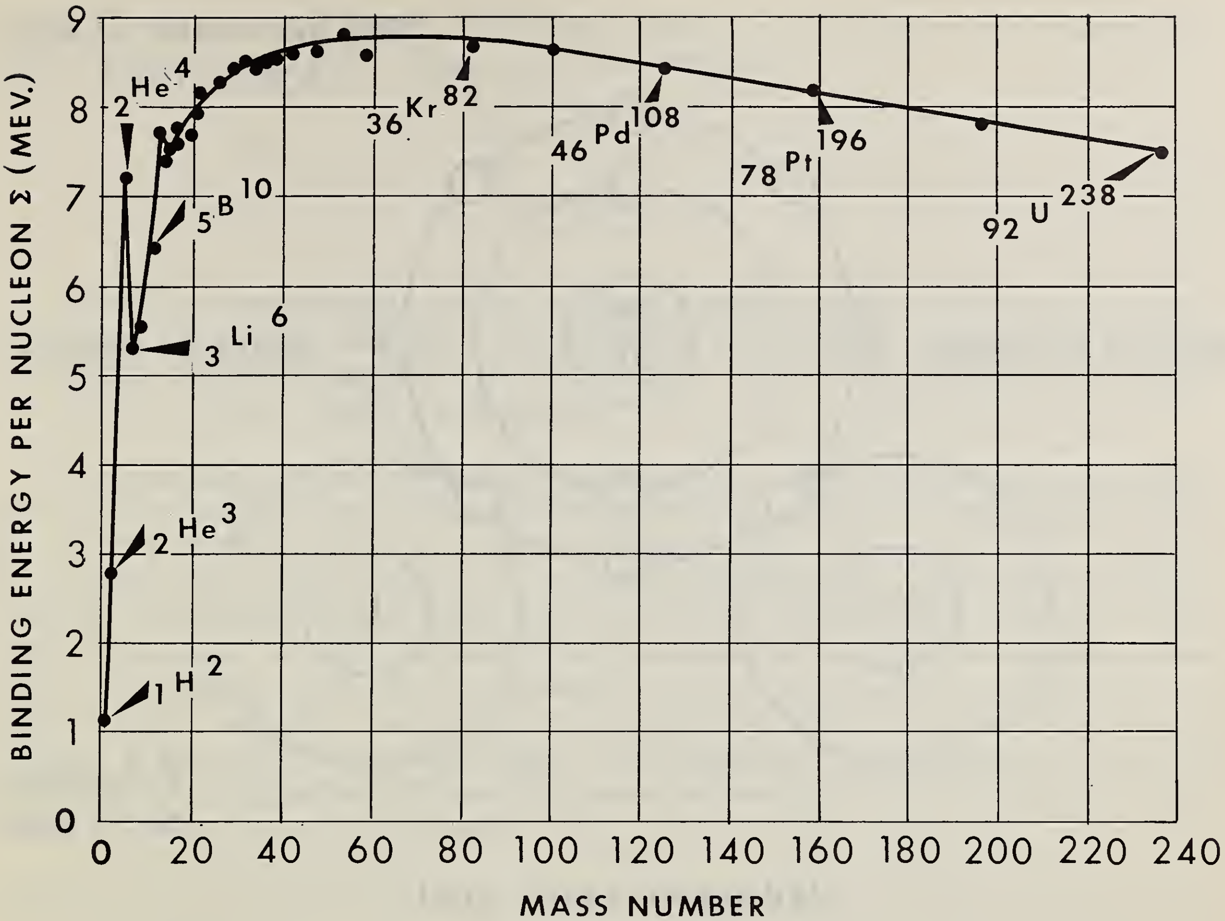

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Figure 3.—Binding energy per nucleon.

Atoms are bound together in definite ratios to form molecules. What is the binding force? Why, for example, do the atoms of sodium and chlorine stick together to form a molecule of table salt? It was noted earlier that each atom has a shell structure of electrons revolving about the nucleus and that the first shell or orbit to be complete must contain 2 electrons, the second shell 8 electrons, the third shell 8 or 18 electrons, etc., to obtain stability. The first two shells of the most common isotope of chlorine ($_{17}Cl^{35}$) are complete but the third shell lacks one electron for stability, while the sodium ($_{11}Na^{23}$) atom has one electron left after the completion of the second shell. Thus there must be the tendency for the extra electron from sodium to go over into chlorine to complete the unfinished subgroup of 8 electrons. And as this does happen, we have the transition of an electron and the sodium atom becomes positively charged (by losing a negative electron), and the atom of chlorine acquires a negative charge. Under the forces of electrical attraction between them, the two charged atoms (or ions as they are called) will cling together forming a molecule of sodium chloride. In the same way an atom of oxygen that lacks two electrons in its outer shell will "kidnap" from two hydrogen atoms their single electrons, thus forming a molecule of water (H_2O). (See Fig. 4 - Molecule of Water.)

The atoms with filled or stable outer electronic shells, such as those of helium, argon, neon, and xenon, are completely self-satisfied and do not need to give or take

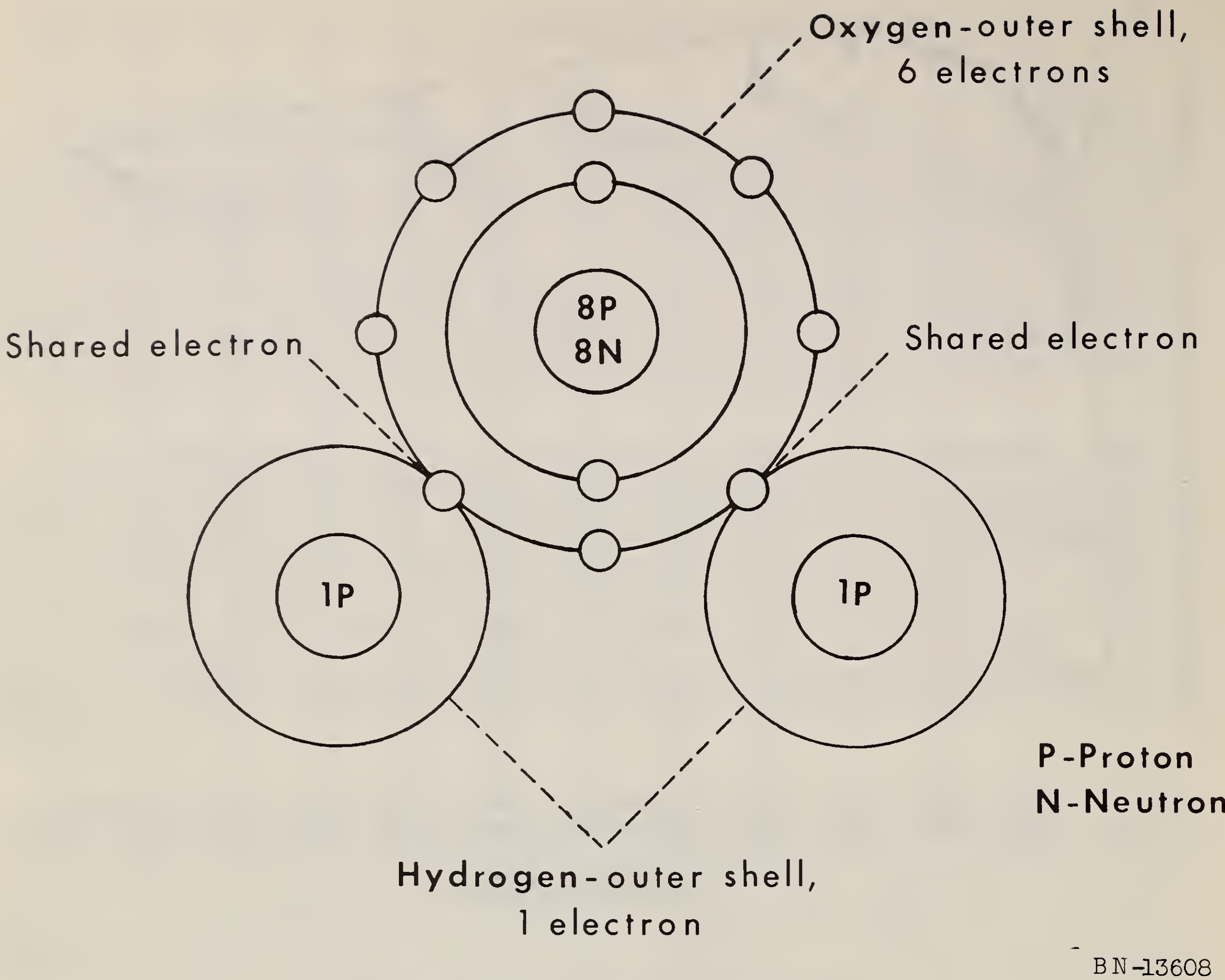

Figure 4.—Molecule of water.

extra electrons. These form the chemically inert "rare gases." The group of elements known as metals differ from other elements in that the electrons of their outer shells are bound rather loosely, and often let one of their electrons go free so that the interior of metal is filled with a large number of unattached electrons. When a metal wire is subjected to electric force applied on its opposite ends, these free electrons rush in the direction of the force, thus forming an electric current.

It is evident that molecules and atoms must be very small, but just how small? As an example, consider a teaspoon of water, which contains about 1 followed by 23 zeros (written mathematically as 10^{23}) molecules of water. This huge figure is more than the number of drops of water in Lake Michigan.

Gases are much less dense than liquids and solids under normal conditions so that a given volume of any material in the gaseous state will contain fewer molecules than an equal volume in the liquid or solid state. If a spoonful of water is heated until it vaporizes into steam, it will then occupy a volume of approximately 5 quarts. The increase in volume has been over a thousandfold; and since the number of molecules present has not changed, the conclusion is that most of the gas or steam consists of empty space. Thus, the gas or vapor does not consist of continuous matter, but of great empty spaces, with rapidly moving molecules of matter scattered in these

spaces. Even with the denser solids and liquids, it can be shown that a large proportion of the volume they occupy is also empty space.

Ions

It has been mentioned that when an atom of sodium gives an electron to an atom of chlorine and the two oppositely charged atoms then combine to form common salt, the charged atoms are known as ions. Therefore, NaCl is the combination of a positive sodium ion and a negative chlorine ion.

It is possible to break any molecule into ion pairs. Even the most complex molecule may be broken apart under certain conditions to form two charged portions of the molecule. Sometimes this is done by solution, as in the case of a salt, by electrical means, as in the case of water, or by physical means, such as bombarding a molecule with minute atomic particles or rays, as in the case with X-rays. In these latter instances it is often merely an electron of one of the atoms in a molecule that may be dislodged. However, this dislodged electron is known as a negative ion because it has a negative charge, and the remainder of the molecule is a positive ion because it has one more proton than it has electrons. So once again an ion pair is formed. And the process, by whatever means it takes place, that causes the formation of ion pairs is termed ionization.

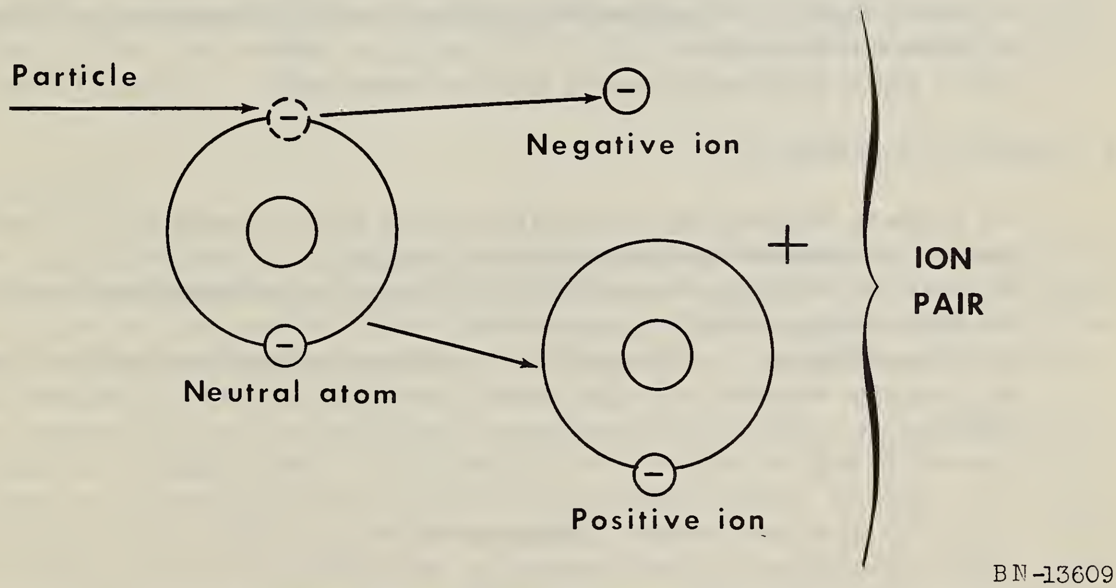

Figure 5.—Process of ionization.

Ionization is very important from a health standpoint as well as from a chemical point of view because of the increased chemical reactivity of ions. As an example, assume that a protein molecule has been ionized with the formation of a free electron and the remainder of the molecule forms the positive ion. It is now unstable because of its need for a negative charge to neutralize its own charge. This neutralization

usually takes place either through rearrangement of its own internal structure or by combining with an available "electron rich" element or molecule. And many times this rearrangement or combining is very detrimental to living tissue. In some cases the result of this chemical change so alters the character of the protein that it is no longer of value to the living plant or animal. If this condition should occur in large numbers of complex and vital molecules, the health of the living organism would be jeopardized.

Questions

1. Matter, considered from a volume standpoint, primarily consists of:

   a. nuclear material,
   b. electrons,
   c. empty space, or
   d. ions.

2. Molecular structure is maintained by:

   a. nuclear attraction,
   b. nuclear repulsion,
   c. electronic motion, or
   d. electronic sharing.

3. An isotope is an atom with:

   a. the same number of neutrons but different number of protons as other atoms of the same element,
   b. a net electrical charge,
   c. the same number of protons but different number of neutrons as other atoms of the same element, or
   d. one or more electrons removed from its outer orbit.

4. Ionization is defined as:

   a. the process whereby an electrically neutral atom or molecule is transformed into a body possessing a net electrical charge,
   b. the process whereby two nuclei of the same element are produced which have the same charge but different masses,
   c. the conversion of one element into a different element by nuclear change, or
   d. the process whereby very fast atomic particles or rays are emitted from the nucleus.

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RADIATION[1/]

It was a little over 60 years ago that the French physicist Henri Becquerel discovered that uranium emitted rays energetic enough to penetrate an opaque paper and cause impressions on photographic emulsions. This occurred even when the plate was protected by sufficient paper covering to assure that even the strongest light could not affect it. Becquerel reasoned that there was something associated with uranium which produced very penetrating rays, which, although not in the visible light range, behaved similarly to light and could blacken a photographic plate. That these rays were not appreciably retarded by the usual covering of the plate was evidence of their great penetration. The Curies carried on Becquerel's work, and showed that the active material causing these rays was not uranium itself, but a hitherto undiscovered element which occurred in very minute quantities along with uranium. They called this new element radium. Radium is always found with uranium in natural ores because uranium is an unstable substance which slowly decomposes to radium.

Particles and Waves

In further study it was revealed that radium is decomposing at a measurable and fixed rate into another element, a heavy, chemically inactive gas known as radon. At the same time the radium is giving off certain radiations that are divisible into three distinct classes.

Alpha Particles

One type of radiation, called alpha particles, consists of a number of fast moving helium ions. Recalling the picture of the helium atom—two protons, two neutrons, and two electrons—an ion can be formed by stripping off one or both of the electrons. Actually, both electrons are missing and the alpha particle is simply a helium nucleus.

The alpha particles are moving with considerable velocities—about 20,000 miles per second, or roughly from 1 to 10 percent the velocity of light. Because of their high velocities, the particles have high kinetic energies (kinetic energy is the energy produced by motion.) They are able to penetrate several centimeters of air, or thin foils of metal less than a millimeter in thickness before losing their energy. Alpha particles lose a little energy each time they collide with another atom, until finally stopped. The energy of the collisions is dissipated, not as heat but in knocking out the electrons from the atoms with which the alpha particle collides. By such collisions ions are formed. Thus, the alpha particle leaves a number of ionized atoms in its wake, and if these ions were observable an ionized path would show where the alpha particle has been.

1/ Prepared by James D. Lane, Meat Inspection Division, Agricultural Research Service, U. S. Department of Agriculture.

Beta Particles

Another type of radiation from the radium is known as beta particles. The beta particles are nothing more than streams of fast moving electrons, which have been thrown out of the radium nucleus. In essence this particle is formed when a neutron in the nucleus splits to form a proton and an electron—the proton remaining in the nucleus and the electron being cast off to form the beta particle. This may be represented by $n \longrightarrow p + e$.

Beta particles travel several hundred times farther than the alpha particles, either in air or metal, before coming to a standstill. This is logical, since the mass of the alpha particle — two protons plus two neutrons — is approximately 7500 times greater than that of the beta particle. Thus, a beta particle, with the same energy as an alpha particle, will move much faster than the alpha particle, and go farther before its velocity is brought to zero by collisions with the atoms which it ionizes.

This penetration can be realized by comparing the difference between driving a truck into a forest and shooting a rifle bullet into a forest. In all likelihood the bullet will penetrate much farther than the truck before coming to a stop. Evidently when the beta particle will not ionize as many atoms for a given length along its path as will the alpha particle if their energies, and hence the number of ions which they can form are equal. Although the energies of the alpha and beta particles are not exactly equal, they are of the same order of magnitude, so that the conclusions are valid.

Gamma Rays

A third type of radiation from the radium nucleus, known as gamma rays, does not consist of particles at all. It behaves very much like light, or better, like X-rays of high frequency, all a form of electromagnetic radiation. Gamma rays move at the speed of light and with a wave motion. They differ from light only in having a much higher frequency; or putting it another way, their wavelength is much shorter. In fact, this is the main distinction between different types of electromagnetic radiations, including radio waves, radar, radiant heat, infra-red, visible light, ultraviolet, X-rays, gamma rays, and cosmic rays. The sequence given is in order of increasing frequency and penetrating power. In order to stop gamma rays from radium, several inches of lead or concrete are required, while several feet of lead or concrete are necessary for shielding when encountering gamma rays from a very strong source such as atomic explosions. Obviously, gamma rays are very penetrating, much more so than alpha and beta particles which can be stopped by much thinner sheets of metal.

Radioactive Decay

In the discussion of the decay of radium a number of terms were used which must be well understood in all future work and in understanding of radiation. As an example, the term "decay" of an element is used in a slightly different sense than the usual meaning of the word. Normally decay would mean to rot, decompose, or

waste away. However, in nuclear physics, decay refers to the disintegration of the nucleus of an unstable atom by means of the spontaneous emission of charged particles of rays. So here the term decay means radioactive decay and indicates that the nuclei of the atoms are unstable.

In radioactive decay the nucleus of an unstable atom breaks down, with the accompanying release of energy in the form of high speed particles or rays ejected from the nucleus, and the consequent change in nuclear structure forms an atom of a different element. Also, the high energy alpha particles, beta particles, or gamma rays released in decay always cause ionization of the atoms these particles or rays encounter in the dissipation of their energy. And this ionization, when it occurs in any form of life, is detrimental to the health of that organism.

Figure 6 demonstrates how a nucleus decays from a parent to a daughter with the emission of an alpha or beta particle. The daughter is in an excited state, however, and the excess energy is released as gamma radiation. Since gamma radiation as a rule is the result of such a decay, it will nearly always be accompanied by either alpha or beta emission. There are many nuclear decay patterns though that are not accompanied by gamma ray emission. This is because not all daughter nuclei are left in an excited state.

The upper decay chain in Figure 7 represents the decay of the fission product krypton 90. It will be seen that the half-life of krypton 90 is 30 seconds and it decays with the emission of beta particles and gamma rays to rubidium 90. This has a half-life of 2.7 minutes and also decays with a beta particle and gamma ray to strontium 90. Strontium 90 has a half-life of 28 years and decays by beta emission forming

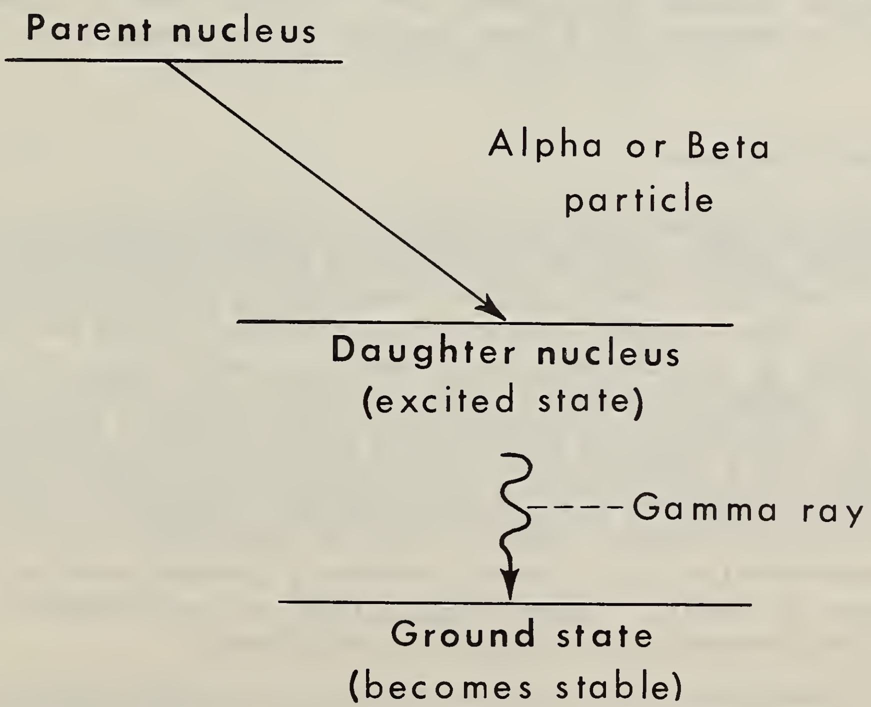

Figure 6.—Emission of gamma radiation in radioactive decay.

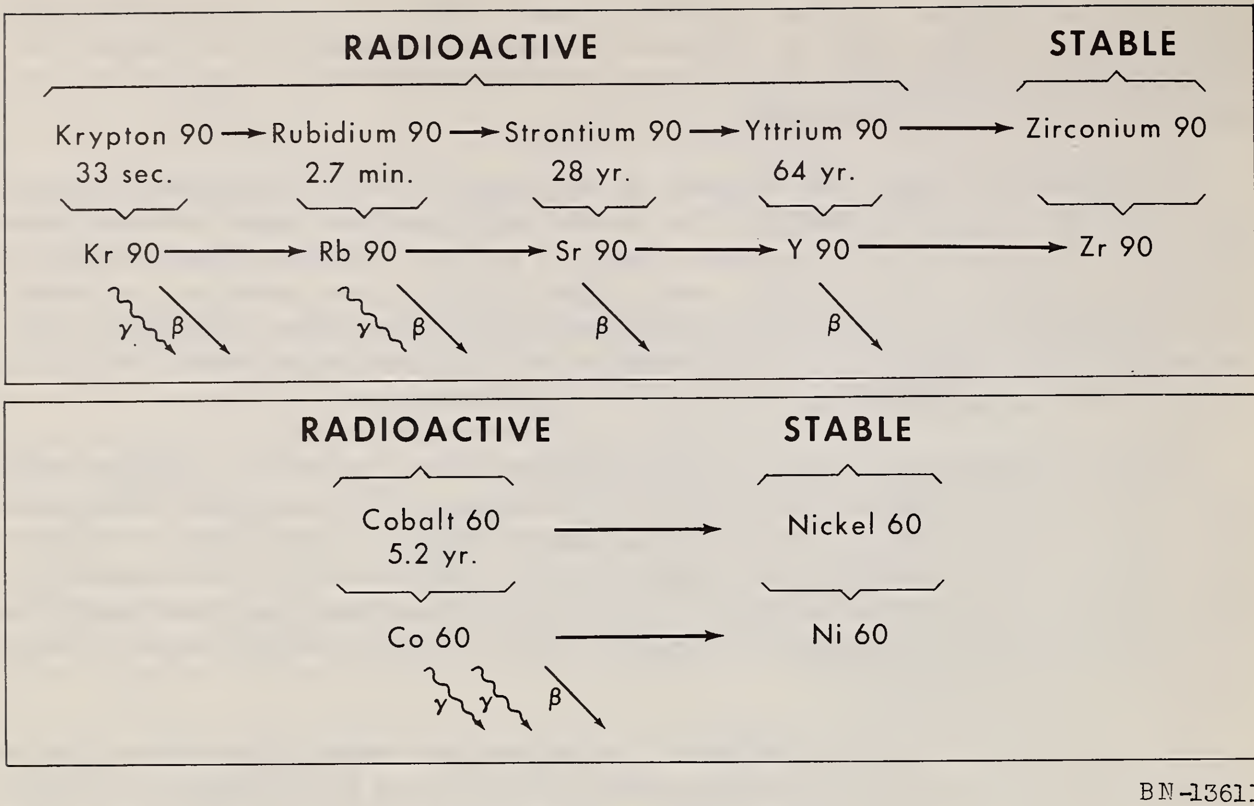

Figure 7.—Radioactive decay.

yttrium 90 with a half-life of 64 hours. This then decays with the emission of another beta particle to zirconium 90 which is a stable product and not radioactive. The lower schematic drawing demonstrates how cobalt-60 with a 5.2 years half-life decays with the emission of a beta particle and two gamma rays to form stable nickel-60.

Electromagnetic Radiation

In describing gamma rays as a form of radiation encountered in radioactive decay of radium, gamma rays were defined as a form of electromagnetic radiation. This type of radiation is not a particle, hence has no mass, but consists rather of units of energy termed photons which travel with the speed of light and have a definite wavelike quality. It is of the same type of energy as visible light, but is much more penetrating of opaque materials. A photon of electromagnetic force is essentially a unit of energy traveling with the speed of light and motivated by the interaction of an electrical field and a magnetic field. In the case of radio (another form of electromagnetic energy), electrons in the sending antenna are accelerated back and forth along the wire at a frequency determined by the generating equipment. It is known that this accelerated electric charge produces a changing electric field which in turn produces a changing magnetic field. Thus an electromagnetic disturbance originates at the antenna and is propagated outward from it.

Electromagnetic Spectrum

The known electromagnetic radiations may be arranged on a wavelength spectrum. The spectrum is divided into several regions, but one must realize that these are

arbitrary and not at all rigid. In the main, the divisions are based upon the methods used to produce the radiation and it is possible to produce a given frequency by two or more methods. As previously noted, the regions into which the spectrum is usually divided are electric waves, radio waves, radar, radiant heat, infrared, visible, ultraviolet, X-rays, gamma rays, and cosmic rays, in order of increasing frequency.

The range of electromagnetic frequencies already known is enormous. Electric powerlines radiate electromagnetic waves at the generator frequency which is usually 60 cycles per second, but it is not difficult to generate much lower frequencies. Of the whole spectrum the part taken up by visible light is very small. At the high frequency end of the spectrum, frequencies of 10^{23} cycles per second are found. (See Fig. 8 - The Electromagnetic Spectrum.)

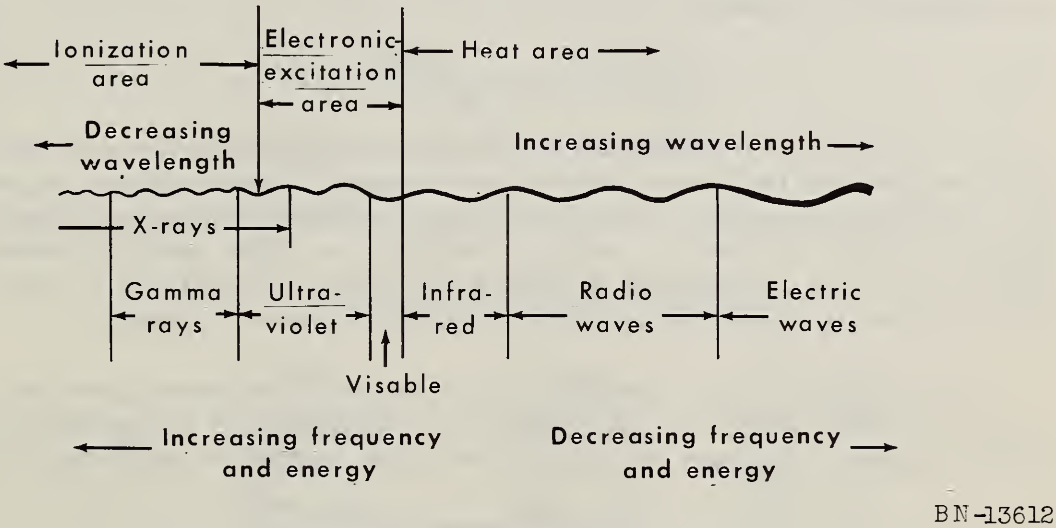

Figure 8.—The electromagnetic spectrum.

Other Radiations

In addition to the alpha, beta, and gamma types of radiation, there are other types sometimes associated with artificial radioactivity. Although these forms will not be discussed in detail, some mention as to what they are and how they differ from the three usual types should be made.

Positron particles are similar to beta particles with one major exception: They are positively charged. Thus, the positron can be considered to be a positively charged high speed electron which originates in the nucleus. This occurs when a proton loses its positive charge and becomes a neutron. This can be represented as $p \longrightarrow n + e+$. An example of positron emission is the decay of fluorine-18 to oxygen-18:

$$_{9}F^{18} \longrightarrow {_{8}O^{18}} + e+$$

Orbital electron capture is the process of decay, which may occur in both natural and artificial radioisotopes, in which the unstable nucleus absorbs an electron from one of the orbital shells, which in effect converts a proton into a neutron. The electron might come from an outer shell, but capture from the inner shell is most probable. As the inner shell is known as the "K shell," this particular reaction of electron capture is often called K-capture, to indicate the origin of the electron.

On removal of the K electron, those from other shells will drop successively into the vacant spaces with the emission of X-rays of definite characteristics. This electron capture causes no change in atomic weight, but decreases the atomic number by one unit, as is the case with positron emission. This is represented as $p + e \longrightarrow n$. An example is the decay of vanadium-48 to titanium-48 as shown by the equation

$$_{23}V^{48} + e \longrightarrow {}_{22}Ti^{48}$$

Transmutation

When radium emits an alpha particle, it decays to produce radon. This reaction can be shown as follows:

$$_{88}Ra^{226} \longrightarrow {}_{86}Rn^{22} + {}_{2}He^{4}$$

In fact, when any radioactive nuclide decays by alpha or beta emission, a transmutation occurs. The decay product or "daughter" product, as it is usually called, has become an atom of a new element with chemical properties entirely unlike the original "parent" atom. A nucleus emitting an alpha particle disintegrates to a daughter element, reduced in atomic number by 2 and reduced in atomic weight by 4; as is shown by the decay of radium by alpha emission to radon.

In the case of beta emitters, the nucleus of the parent gives off a negatively charged particle resulting in a daughter more positive by one unit of charge; the atomic number increases by one but the mass number is unchanged. For example:

$$_{82}Pb^{214} \longrightarrow {}_{83}Bi^{214} + e$$

A nuclear decay reaction resulting in a transmutation generally leaves the resultant nucleus in an excited state. Nuclei, thus excited, may reach an unexcited state by the instantaneous emission of one or more gamma photons. Both of the transmutation examples shown above would be accompanied by gamma emission. Although most nuclear decay reactions do have gamma emissions associated with them, there are numerous radionuclide species which decay by particulate emission with no gamma emission.

Radioactive decay results in increase or decrease of the nuclear electric charge and of the number of orbital electrons, with resulting changes in chemical and physical properties of the atoms. The change is always in the direction of greater nuclear stability. In some cases, the changed atoms are stable; in others, they are unstable and a successive chain of decays may have to take place before a stable isotope is reached.

Penetrating Range of Radiations

As noted, the particulate (alpha, beta) radiations that are emitted from the nucleus have limited penetrating range in matter. For example, an alpha particle may be emitted with one million electron volts of energy. An electron volt is the unit

of energy used in discussing radiations and is defined as the unit of energy equivalent to the amount of energy gained by an electron in passing through a potential difference of one volt. Abbreviations used are ev for electron volt, Kev for thousand electron volts, Mev for million electron volts, and Bev for billion electron volts. A Mev alpha particle will penetrate about 1.5 cm. of air or 15 microns of tissue while a 1 Mev beta particle will penetrate about 4 yards of air or 0.4 cm. of tissue. By the time these radiations have penetrated this distance in matter they have lost all their kinetic energy through the ionization process. It is estimated that an average of 35 electron volts are lost per ionization event. From this it can be roughly estimated how many ionizing events will be caused by each radiation of a known energy.

Half-Thickness

One does not speak of a penetrating range for the gamma ray. Instead range can be referred to in terms of half-thickness. One half-thickness of any material will reduce the gamma ray intensity by one-half. The half-thickness for a 1 Mev gamma ray is about 1 cm. in lead or about 100 yards in air. Therefore, there is a gamma intensity of one-half of the original value after penetration of 1 cm. of lead; one-fourth (1/2 x 1/2) of the original value after penetration of 2 cm. of lead, etc. This relationship holds true regardless of the original value of the gamma intensity.

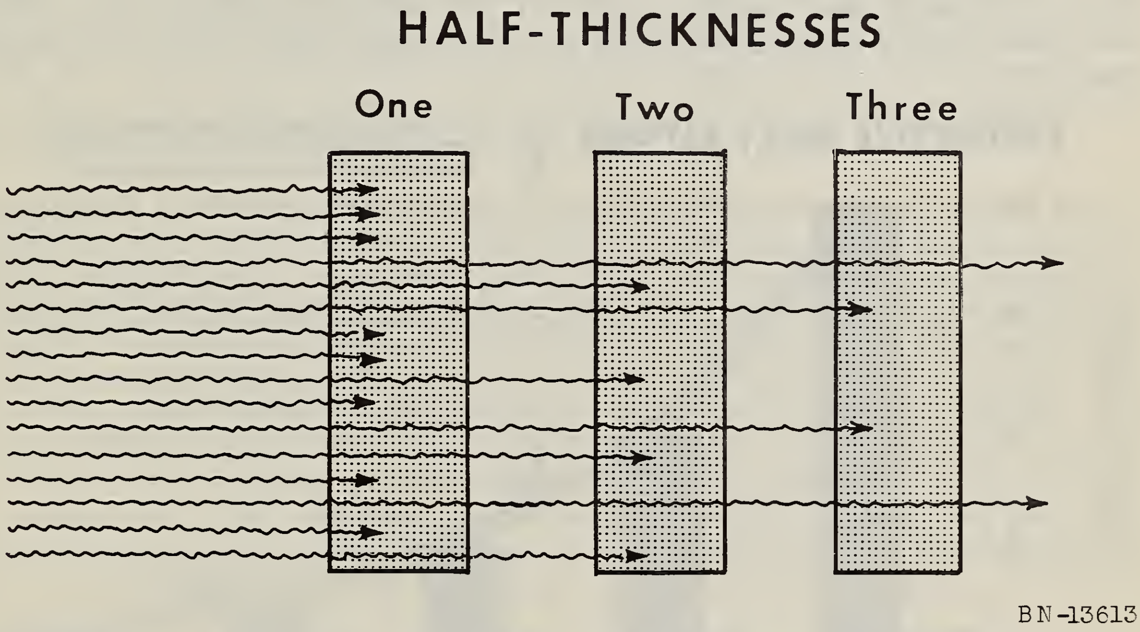

Figure 9.—Concept of half-thickness shielding for electromagnetic radiation.

Radioactive Decay

Half-Life

For any particular atom, decay does not take place gradually. It is an all-or-none reaction. Radioactive decay can neither be slowed nor hurried by any means.

Among a number of identical radioactive atoms, disintegration events occur strictly at random so prediction of when any specific nucleus will decay is not possible. This very randomness, however, favors statistical analysis of radioactive decay. If a large number of atoms of the same radioisotope are considered, and small bits of matter do contain fantastic numbers of atoms, the number that will disintegrate in any given length of time can be estimated with great accuracy. For radioactive atoms of every kind, the number decaying during a given time is proportional to the number originally present. If the interval chosen is that in which 50 percent of the atoms present will decay, then in each successive identical interval 50 percent of the remaining radioactive atoms will decay. Time intervals of this sort are called radioactive <u>half-lives</u>. Put another way, decay time or half-life of a radioactive isotope is the time required for a given quantity to decompose so that only half of it remains.

It is important to remember the following points — the decay time is independent of the amount of material present, as long as there are a large number of atoms, and the decay time has a constant value for any particular isotope. The half-life varies greatly for different radioactive elements. Thus, the half-life of uranium-238 is several billion years, while that for some of the intermediate products in its decay to radium and thence to lead, is only a millionth of a second. Obviously, an element with a large decay time or long half-life is more stable than one with a shorter half-life. Also, radioactivity appears to be theoretically possible in a number of isotopes now considered to be stable. It may be in time to come, when they can measure decay more accurately, our scientists will find that still other elements are radioactive with half-lives of quintillions (10^{12}) or more years. (See Fig. 10 - The Meaning of Half-Life.)

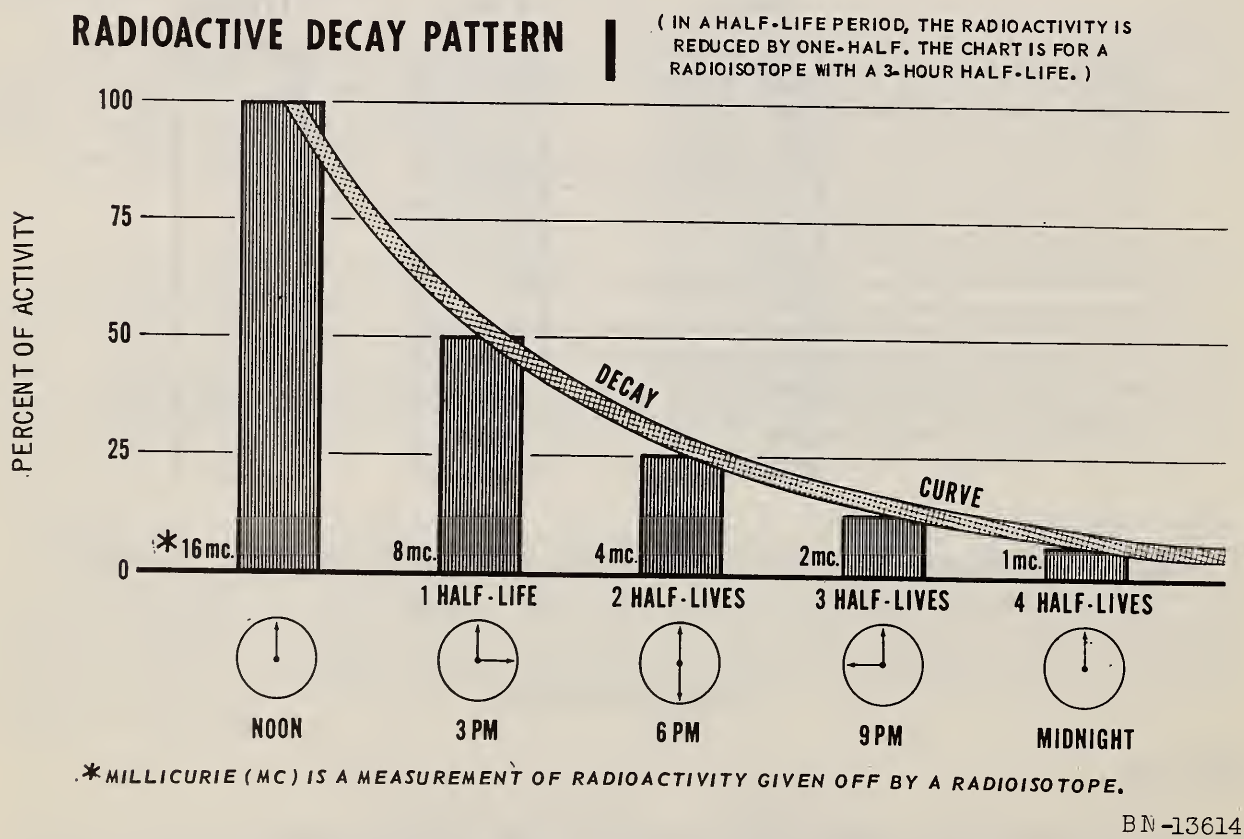

Figure 10.—The meaning of half-life.

In general, the importanr fact of radioactivity is that energy release in the form of harmful radiations is an integral part of the process. The concern with radioactive substances is not because they decay, but because in decaying alpha, beta, and gamma radiations are emitted that may affect plants, animals, and people.

Naturally Occurring Radiation

Cosmic Rays

A question here might be, what are the sources of these radioactive particles and rays? It has previously been mentioned that cosmic rays occupy the part of the electromagnetic spectrum with the highest frequency or shortest wavelength. This would indicate that they have the highest energy of all the electromagnetic radiations known to man. Although there is still much research being done on cosmic rays, the accepted theory now is that the rays are not really "rays" at all, but are very high energy particles traveling through interstellar space to us with almost the speed of light and the rays are produced when the particles pass close to nuclei of the atoms that form the atmosphere. The primary high speed proton (which is the form of most of the particles) gradually loses its original energy, which is emitted in the form of very high energy gamma radiation all along its track. The gamma photons being emitted by the proton particle then change to an electron pair (one positive, the other negative) by a curious transformation of energy to mass, and the positive and negative electrons rush along the path of the primary particle. This transformation of energy to mass is sometimes pictured as $\rightsquigarrow < \genfrac{}{}{0pt}{}{e^-}{e^+}$.

Having still a very high energy these electrons give rise to more gamma radiation, which, in its turn, produces still more new electron pairs. This process of successive multiplication is repeated many times during the passage through the atmosphere, so that the primary proton finally arrives at sea level being accompanied by a swarm of secondary electrons, half of them positive, the other half negative. It goes without saying that such cosmic ray showers can also be produced when fast protons pass through massive material bodies where, due to the higher density, the branching processes occur with much higher frequency. Thus, the term "cosmic ray" is actually a misnomer because the primary particle is a very high energy proton rather than a ray. However, rays of extremely high frequency are produced by the interaction of this proton on other atoms and these rays were what were first measured and thought once to have originated from outer space themselves.

Earth Radiations

In addition to the cosmic rays there are a number of naturally occurring radioisotopes in the earth. As was previously discussed, in the heavier elements the ratio of neutrons to protons becomes larger and larger in order to maintain nuclear stability. However, when the neutron to proton ratio exceeds 1.5 to 1, as is found in bismuth ($_{83}Bi^{209}$), there are no completely stable nuclei. Not only are all elements heavier than bismuth unstable, but there are also several elements lighter than bismuth with unstable isotopes that may be found in nature. These are found when the neutron to proton ratio is not within the stability range for that element.

Shown below are several naturally occurring radioisotopes:

Element	Isotope	Half-Life	Type of Emission	Energy (Mev)
Potassium	${}_{19}K^{40}$	1.3×10^9 years	Beta, gamma	Beta (1.33) Gamma (1.46)
Rubidium	${}_{37}Rb^{87}$	6×10^{10} years	Beta	Beta (0.27)
Samarium	${}_{62}Sm^{147}$	1.4×10^{11} years	Alpha	Alpha (2.18)

Nuclear Stability

By way of summary, it can be stated that nuclear stability is governed by the particular combination and arrangements of neutrons and protons in a given nucleus. If the combination of neutrons and protons does not fall within a "stable range," then the nucleus is unstable, which is tantamount to saying the nucleus is radioactive. An unstable nucleus attempts to achieve stability by changing its configuration or ratio of neutrons and protons by means of spontaneous disintegration, or radioactive decay.

Artificially Produced Radiation

The current surge of interest in ionizing radiation was stimulated by the development of atomic energy and employment of the atom bomb. As a consequence, there is a tendency to associate radiation with radioisotopes to the exclusion of other sources. But despite this common trend, it should be kept in mind that ionizing radiations can be produced by machines as well as by radioactive substances.

Machine Sources

There are many kinds of machines that produce radiations. Fluoroscopes and radiographic machines are used in medicine and industry, primarily because the rays they produce penetrate opaque materials and make their internal structure visible by casting shadows. Some radio transmitters, high voltage rectifiers for changing alternating current to direct current, and high voltage projection-type television receivers (the picture circuits of ordinary, direct-view television receivers in use today present no radiation hazard) generate X-rays as a byproduct of their operation. Cyclotrons, betatrons, and similar machines when used in research to accelerate protons, electrons, and other charged particles, also are a source of ionizing radiations.

As is the case with radiations produced by radioactive decay, ionizing radiations are produced by machines through excitation of atoms or parts of atoms. Also, they are absorbed by producing energy and chemical changes in other atoms and molecules.

These changes are identical with those produced by the rays from isotopes. Once an ionizing radiation has emerged from its source it is no longer possible to determine whether it was produced by a machine or by radioactive decay. X-rays, gamma rays, and ionizing particles detected in passage bear no markings to indicate whether they were made by man or by nature.

X-Rays

X-rays are produced in machines by bombarding a metal or other dense target with a stream of high-speed electrons. The rays result when the electrons suddenly lose speed in the intense electric fields surrounding the target atoms. The production of X-rays by machines is carried out in large vacuum tubes somewhat similar to ordinary radio tubes.

The two major electrodes are fixed at opposite ends of the tube, within the vacuum. One electrode is the cathode. The other is the anode or target. High voltage enables an electric current to leap the gap between the electrodes. When this current, which is made up of electrons, strikes the target a part of the energy is converted into X-rays that pass out through the walls of the vacuum tube much as light passes out of an electric light bulb.

X-rays emerge in all directions from the target. It is customary to use only a small beam of X-rays that can be directed where it is needed. For this reason, in modern equipment, the tube is enclosed by a shielding layer of lead or other dense material, leaving only a small opening through which the useful beam may pass. The higher the voltage of the electric current used to activate the tube, the more penetrating the resulting rays will be. Therefore, X-ray tubes use high voltages, from 50 thousand to more than 10 million volts.

Induced Radiation

Induced radiation first was clearly demonstrated with the building of particle accelerators, such as cyclotrons and betatrons, in 1932. These machines were built by physics research laboratories for the purpose of proving or disproving the various theories of nuclear physics by means of bombarding nuclei with extremely fast moving subatomic particles. Electrons, protons, or neutrons were usually used for this purpose and the effects of these high speed projectiles on various nuclei were studied in an attempt to gain new insight into atomic structure. However, the first such experiment in this field utilized an alpha particle as the projectile and aluminum was the target material:

$$_{13}Al^{27} + {}_{2}He^{4} \longrightarrow {}_{15}P^{30} + {}_{0}n^{1}$$

The resultant nucleus of phosphorus-30 was observed to be radioactive and decay with a half-life of 2.6 minutes.

This work stimulated similar experiments throughout the world and as a result, radioactive isotopes of nearly every element in the periodic table can be produced by "bombarding" a stable isotope with charged particles, neutrons, or in certain instances, photons. Over 1,000 unstable nuclear species are now listed in isotope tables.

Carbon-14

Carbon-14 has been in the news for some years now because of the ability to measure the amount of carbon-14 contained in wood. By this measurement the age of wood and other plant materials uncovered by archeologists can be closely determined and thus the age of extinct cultures ascertained. It is interesting to note that this is another form of induced activity by means of the continual action of cosmic rays on atmospheric nitrogen to convert the nitrogen-14 to carbon-14. This radioisotope has a half-life of 5,580 years, and by measuring the ratio of carbon-14 to carbon-12 the approximate age of the piece of wood can be determined, or at what time the plant was growing and incorporating carbon into its structure.

Radiation in Research

Since the advent of nuclear reactors, radioisotopes may be formed almost at will. This, needless to say, has been an enormous boon to the field of medical research and now the rare naturally occurring radium has been supplemented by many different artificially induced radioactive materials for use in research, therapy, and diagnostic work. As an example, cobalt-60 is now often used as a radioactive source material. Cobalt-60 is "manufactured" by placing tubes of cobalt-59, which is the stable isotope found in nature, into an atomic reactor for a specified length of time. The neutrons released by the fissioning of the fuel in the reactor bombard the cobalt-59 and many nuclei absorb neutrons to become radioactive cobalt-60. This reaction is shown as:

$$_{27}Co^{59} + {_0}n^{1} \longrightarrow {_{27}}Co^{60}$$

Many other elements can be similarly induced to a radioactive state by neutron absorption.

Nuclear Fission

In referring to neutron induced radiation, it should be remembered that this type of radiation can be brought about by the detonation of a fission or fusion type nuclear detonation, as well as occurring in a nuclear reactor. Here too, many neutrons are released and some induced radioactivity may be found in the vicinity of the detonation. The elements most usually affected here are those normally found in the terrain over which the detonation occurs. This feature of a nuclear explosion is not so important to life, however, because of the relatively short range of neutron activity and the overwhelming effects of heat and blast as agents of destruction in this area.

Fission Products

Fission products and the story of nuclear fission begins in 1934, just after the neutron was discovered. Enrico Fermi and his associates subjected most of the elements in the periodic table to neutron bombardment. Generally, the target nuclei

were observed to capture the neutron, become unstable, and subsequently emit a beta particle in returning to a stable state. This resulted in a new element one unit of mass higher than the original atom. Since uranium was the heaviest element in the periodic table at that time, Fermi was naturally curious to see if he could create a new element by using uranium as a target for the neutrons. Instead of producing an element heavier than uranium, as Fermi had expected, this resulted in a combination of radioactive products which could not immediately be identified. Eventually, after much scientific effort, two other workers identified the radioactive products as atoms of lighter elements that had been formed by the actual splitting of the uranium nucleus. The splitting of a heavy atom into two or more large fragments with the release of energy is called fission. It was first demonstrated by Fermi's work. One typical reaction of the fission of uranium is:

$$_{92}U^{235} + {}_{0}n^{1} \longrightarrow {}_{36}Kr^{90} + {}_{56}Ba^{143} + 3n$$

Fission Product Decay

When an atom of uranium fissions to give two atoms of lower atomic weight, it has been found the reaction may take place in quite a large number of different ways, each yielding a different pair of fission products. In fact, it has been found that at least 60 different nuclides may be formed by the fissioning process, and as these fission products are all radioactive and from the instant of their formation begin decaying into other products by emitting beta particles, often accompanied by gamma radiation, as many as 200 isotopes may be formed during the decay process. The products of the original decay are in turn usually radioactive, forming still other products which may likewise be radioactive.

On the average, each of the 60 or more original fission products will undergo 3 stages of decay before it is converted into a stable isotope. The process of radioactive decay will be practically completed in the case of some isotopes in a few seconds or a few minutes; with others it will require many years.

Thus, fission products of uranium or plutonium are numerous and they in turn form other radioactive products. Each of these has its own half-life, some long, some short, and each has its pattern of radioactivity. By this it is meant that each isotope decays according to its own pattern exactly alike in each instance, with the same release of energy associated with its beta particle or gamma rays. This does not vary and is characteristic for each isotope. And as the process of decay goes on, isotopes are formed which tend to have longer and longer half-lives. Thus, it is not possible to assign a specific half-life to fission products as a whole. However, it is known that the activity of fission products drops off quickly at first and then tends to level out as time progresses. This is because of the very short half-lives of many of the early-formed products and later the longer lived isotopes with their reduced activity assume a greater importance.

Nuclear Fusion

In the fusion process, whereby four atoms of hydrogen fuse forming one atom of helium with the release of tremendous amounts of energy, no radioactive particles

are formed. However, at the present time, each fusion process must be triggered with a fission process so that even with the "hydrogen bomb" radioactive particles will be formed.

The types of fission products will be more fully discussed under the subject of fallout. However, here it is only necessary to emphasize that all fission products are radioactive and are beta and gamma emitters, whereas the fissionable materials themselves, such as uranium and plutonium, are alpha emitters. Consequently, when incomplete fission is encountered, alpha as well as the beta and gamma radiation may be found in fallout.

Absorption of Radiation

Ionization

As has been described earlier, all radiation is essentially the propagation of energy through space. This is in the form of kinetic energy in the case of particulate radiations, or in the form of inherent energy in the case of electromagnetic radiations. But, in either case, the absorption or neutralizing of this energy is by the process known as ionization. Ionization is the process whereby a neutral atom or molecule is transformed into a body possessing a net electrical charge. This is accomplished by the removal of one or more of the orbital electrons from the atom, as the result of interaction with radiation. And as the freed orbital electrons also possess an electric charge, they are also known as ions and thus ion pairs are formed, each possessing an electrical charge. The negative ion is the released electron and the positive ion is the fragment of the atom or molecule remaining after the removal of the orbital electron. (See Fig. 11 - Ionization.)

Specific Ionization

The measure commonly used in comparing ionizing powers of the several ionizing radiations is called specific ionization. Its value is stated as the average number of

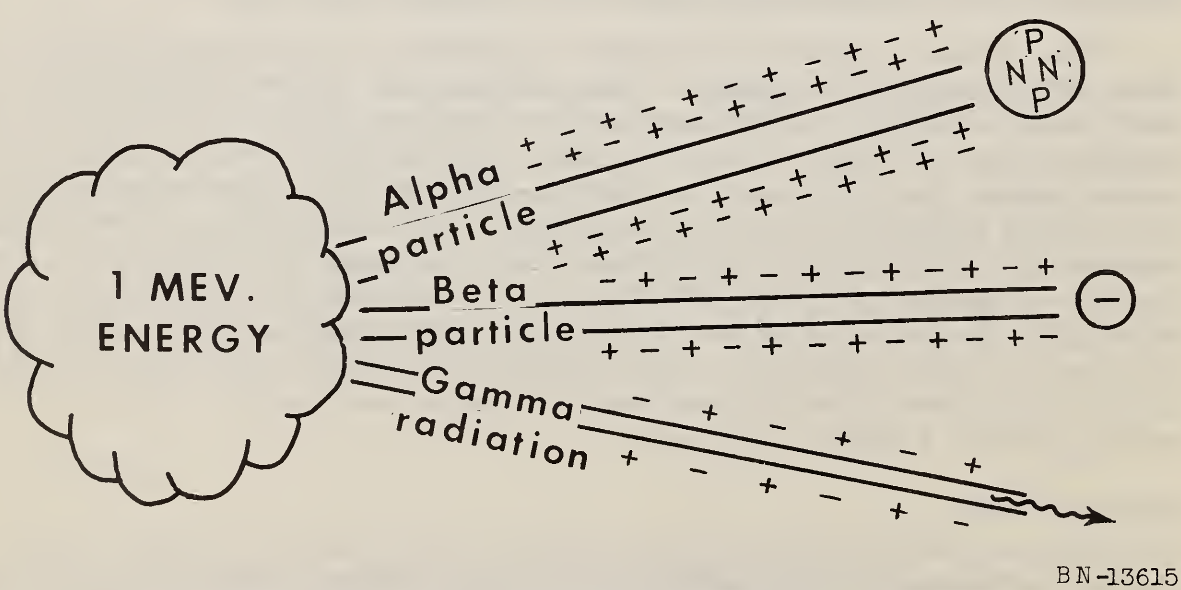

Figure 11.—Specific ionization of radiation.

ionizations or ion pairs formed by an ionizing particle or photon per centimeter of path length in air. This number depends upon the charge and speed of the particle or the energy of the photon.

Alpha particles have large specific ionization values. Since they create many ions per unit of path length, they dissipate their energy rapidly and penetrate only short distances. Alpha particles are normally a hazard to health only in the form of internal radiation.

X-rays and gamma rays have quite low specific ionization values. They ionize sparsely over long paths and are quite penetrative. As a group, these radiations constitute the chief health hazard of external radiation, although gamma rays can be a hazard also as internal radiation.

Beta particles are light in weight and carry single negative charges. Their specific ionization values are intermediate between those of alpha particles and those of gamma and X-rays. They ionize matter somewhat sparsely, dissipate their energies relatively quickly, and are moderately penetrative. Beta particles can be a health hazard either as internal or external radiation. (See Fig. 11 - Specific Ionization of Radiation.)

Particulate Energy Absorption

Alpha particles are seen to have a high specific ionization value because of the relatively large size of the particles. Because of this large size many collisions occur between the alpha particle and orbital electrons so that many ion pairs are quickly formed and soon the energy of the particle is dissipated. It ultimately picks up two electrons and becomes a neutral helium atom. Beta particles act much in the same way but travel much farther in matter before dissipation of energy because of the much smaller size of the particle. Because of this smaller size fewer collisions occur in any given path it follows and hence its specific ionization value is lower.

Electromagnetic Energy Absorption

X-rays and gamma rays ionize matter and consequently are absorbed in quite a different manner than alpha or beta particles. Having no mass they do not produce direct ionization by collision along their path, but are absorbed by three mechanisms known as the photoelectric effect, the Compton effect, and pair production.

In the photoelectric effect each photon retains all of its energy until it impinges upon, and ejects at a high speed, an electron from some atom in the absorbing medium. In this process the photon gives up all of its energy and ceases to exist. The ejected electron, called a photoelectron, dissipates its energy by ionization of other atoms in the same manner as a beta particle.

In the Compton effect the incident gamma photon impinges upon an electron of an atom of the absorbing medium and in the ejection of the electron a photon of lesser energy rebounds or is "scattered" in such a manner as to conserve both energy and

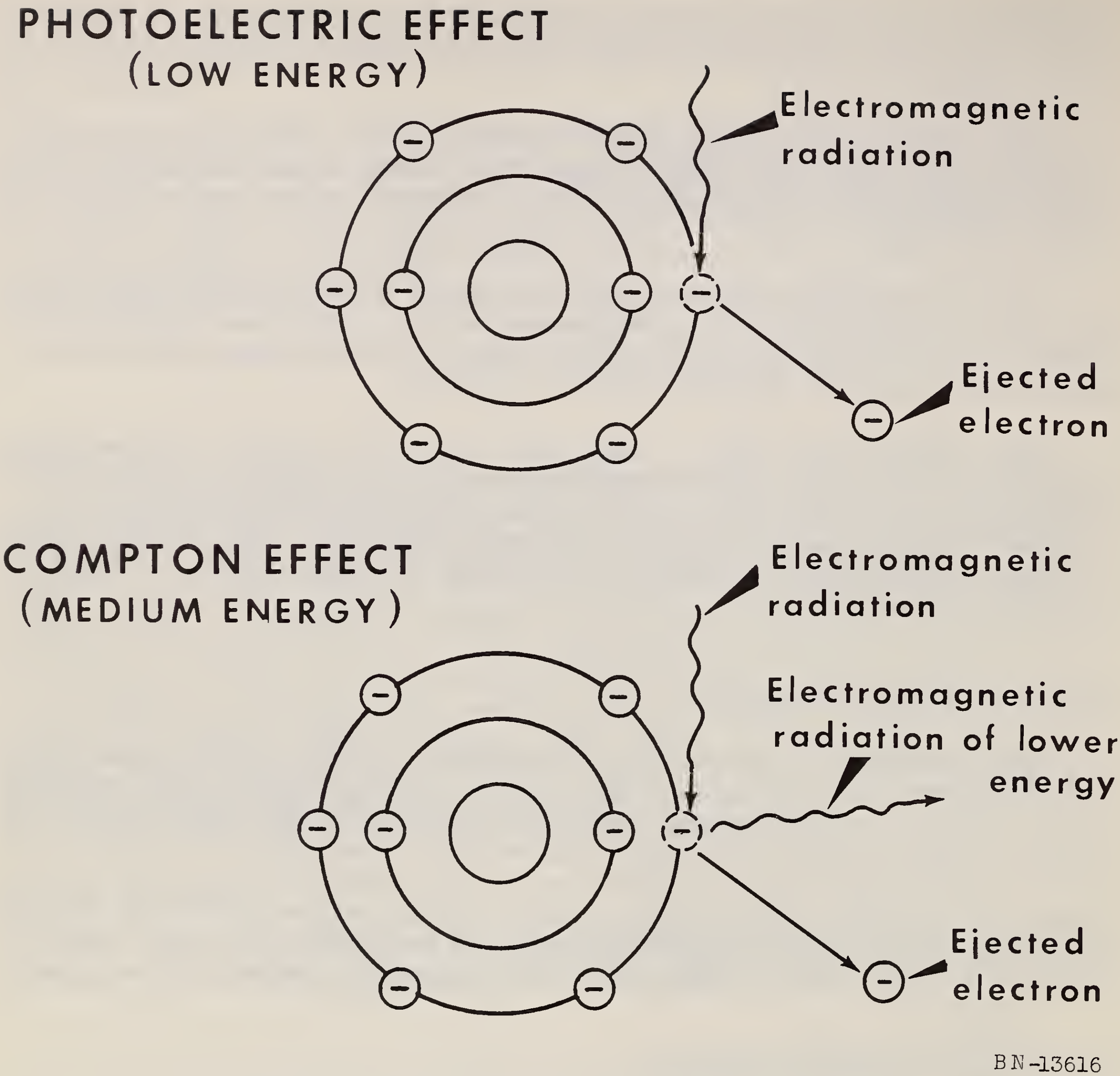

Figure 12.—Ionization by electromagnetic radiation.

momentum. The new photon has characteristics which differ from those of the original incident photon; that is, a lower frequency or less energy. As in the case of the photoelectron, the recoil electron then dissipates its energy in a manner similar to beta particles. The scattered photon is further absorbed by either the photoelectric or Compton process.

In the third absorption process, pair production, some of the energy of the incident photon is converted to mass according to the famous Einstein theory that mass and energy are interchangeable. In this process, occurring only with high-energy gamma rays and cosmic rays, the photon in approaching the nucleus of an atom in the absorbing substance may convert itself into a pair of electrons, one negative and the other positive (positron). The incident photon ceases to exist when this occurs. The creation of such a pair requires 1.02 Mev of energy, thus this process of absorption does not take place for photons of less than 1.02 Mev energy.

The energy of the incident photon not transformed into mass is imparted as kinetic energy to the two particles so formed with half of the excess photon energy being imparted to each particle. The electron is further absorbed by direct ionization along its path. The positron, on the other hand, has a very short life. As soon as it slows down it is neutralized by an electron and the combination of the oppositely charged electrons results in a pair of gamma photons, each of 0.51 Mev energy, which is ultimately absorbed by the photoelectric or Compton effect.

Neutron Energy Absorption

Neutrons, although particles, have no charge and interact with matter quite differently than either alpha or beta particles. Whereas an alpha or beta particle, when passing through a medium, loses its energy primarily by electrical interaction with orbital electrons, the neutron loses energy only by direct collision with the atomic nuclei of the medium through which it passes. These collisions are either of an elastic nature or the neutron is absorbed or captured by the nucleus.

In elastic collisions the neutron transfers appreciable momentum and energy to the target nucleus. An analogy can be drawn between such elastic collisions and billiard ball collisions. The nuclei of lighter elements are more effective than those of heavier elements in deenergizing or slowing down neutrons by elastic collisions. The lighter elements, particularly hydrogenous materials, such as water, wood, and paraffin, have better moderating and absorbing qualities for neutrons than materials such as lead and steel. As in the case of other types of radiation, ionization will be produced in the medium absorbing neutrons.

When the neutron collides with a nucleus, the nucleus will be pushed, and having appreciable momentum and kinetic energy will leave behind one or more of its orbital electrons. This results in the formation of ion pairs; the positively charged ion goes on to produce secondary ionization in a manner similar to the alpha particle. On occasion gamma radiation is emitted when nuclei absorb neutrons by capture.

Secondary Radiation

In this discussion of radiation absorption, interaction occurs beteen the radiation and the orbital electrons, except during neutron absorption. When an electron from an inner orbit is ejected because of collision with a radiation particle, its place is usually filled by an electron from an outer orbit. The filling of these inner orbits is accompanied by the release of excess energy in the form of characteristic electromagnetic radiation (ultraviolet or X-rays). In almost all cases of radiation absorption, such secondary emissions of electromagnetic radiation occur and this follows its own specific absorption pattern.

In only a very few cases will the absorption of this radiation result in the transmutation of elements. Attenuation of radiation is accomplished primarily in the orbital cloud and, although ion pairs are formed, there is no nuclear change in the atom. Ionized matter is generally not radioactive in itself. Material can be subjected to exceedingly high radiation, either natural or artificial, and although much ionization occurs, little or no induced radioactivity can be found. Only in the case of neutron exposure can induced radioactivity be demonstrated.

Workers in radiation hygiene commonly use two standard units of measurement for radiation and radioactivity. These units are the roentgen and the curie. The roentgen (r) is used to express radiation exposure dosage. The curie expresses the quantity of material present in terms of its radioactivity.

Roentgen

The roentgen (r) by definition measures exposure dose from gamma and X-rays only. It is named in honor of Wilhelm Roentgen who made the first practical use of X-rays more than 50 years ago.

The roentgen is defined as that quantity of X- or gamma radiation necessary to produce ions carrying one electrostatic unit of electricity of either sign in one cubic centimeter of air under standard conditions. This unit is applied to both gamma radiations and X-radiations because, except for the sites of their origin in the atom, these two radiations are basically identical. Although the roentgen actually is an expression of the ability of gamma and X-radiations to ionize air, it has come to be used also as a measure of radiation dosage to animals and man.

As one roentgen is an appreciable biological dose of ionizing radiation, for medical-biological purposes, a subunit, the <u>milliroentgen</u> (mr) or 1 thousandth (1/1000) of a roentgen, has been recognized. The International Commission on Radiological Protection recommends that every effort be made to reduce exposure to all types of ionizing radiations to the lowest possible level. The exposure required to take a 14" by 17" medical X-ray picture of a person's chest is about 0.05, or 50 mr. A whole body exposure of about 450, according to authorities on radiation effects, will kill 50 percent of persons so exposed. In man, a whole body exposure of about 100 is expected to produce 10 percent radiation sickness.

Curie

For measuring amounts of a radioactive substance, it has become customary to use the rate of its radioactive disintegration rather than the effects of the radiation it produces or the radiation itself. This is necessary because some radioactive substances emit more than a single radiation with each disintegration.

The curie (c) is the accepted unit of radioactive disintegration. It was named in honor of the Curies for their pioneer work with uranium, radium, and polonium. One curie, biologically speaking, is a very large amount of radioactivity. For practical purposes, a gram of pure radium is one curie of radium. Three smaller units or subunits, the <u>millicurie</u> (mc), 1/1000th curie, the <u>microcurie</u> (μc), 1/1,000,000th curie, and the <u>picocurie</u> (pc or $\mu\mu$c), 10^{12} curie, are frequently used to measure biologically significant amounts of radioactive substances.

One-tenth of a microcurie (0.1 μc) of radium fixed in a human body is considered to be the maximum amount that within a lifetime will produce no noticeable deleterious

effects. The threshold amount of radium fixed in the tissues for production of the most serious effects, leukemia and bone cancer, appears to be of the order of one microcurie.

In addition to the two standard units of measurement commonly used in radiation hygiene, a need has developed for other units of measurement to more accurately gauge effects of radiation.

The Units of Measurement of Ionizing Radiation

A quantity of radiation cannot be measured directly. Instead, it is measured by the ionization produced by the passage of the radiation through a medium. Several units are used to state a measured quantity of radiation. The quantity may refer either to charge, energy, or to biological effect (See Fig. 13 - Charge, Energy, and Biological Effect of Roentgen). Those units of widest acceptance are the roentgen, radiation-absorbed dose (rad), and roentgen equivalent man (rem). The roentgen is a measure of ionization in air due to X- or gamma radiation; the rad measures the energy absorbed by radiation in any material; and the rem relates the effectiveness of the different radiations, in producing biological damage, to the quantity of radiation.

Radiation-Absorbed Dose

The unit of radiation-absorbed dose (rad), is based on the absorption of 100 ergs of energy per gram of material.

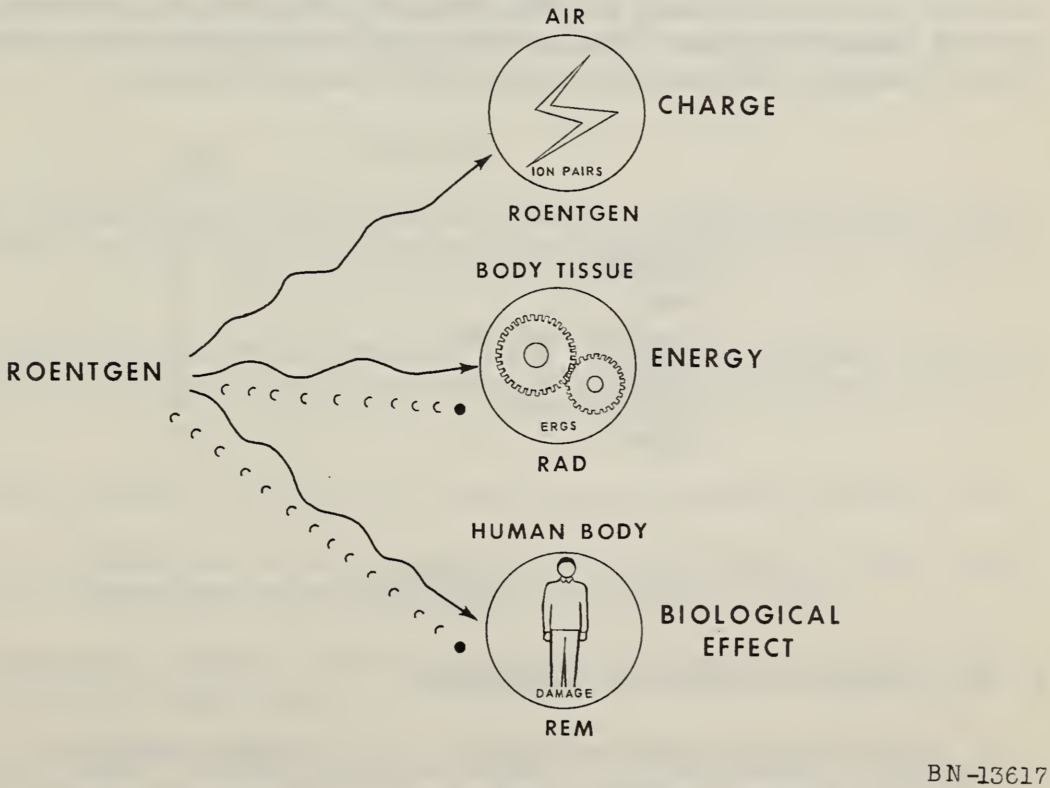

Figure 13.—Charge, energy, and biological effect of roentgen.

Roentgen Equivalent Man (or Mammal)

Roentgen equivalent man (rem) is the dose of any ionizing radiation which, when delivered to man, is biologically equivalent to one roentgen of X- or gamma radiation. So the number of rems is equal to the number of rads multiplied by the RBE for the type of radiation involved (rems = rads x RBE). This term is also interpreted to mean roentgen equivalent mammal and is often utilized in experimental radiation work with mammals. The following is a comparison of units of measurement:

ROENTGEN = 83 ergs/gram dry air
Used in measuring X and gamma radiation in air

rad = 100 ergs/gram any medium
Used in measuring any type of radiation in any medium

↓

rem = rad x RBE
Applies to man and corrects for biological effectiveness of different radiations

Relative Biological Effectiveness

Relative biological effectiveness (RBE) is the ratio of gamma or X-ray dose to the dose that is required to produce the same biological effect by the radiation being studied. This is especially useful in comparing the damage done by different types of radiation. As an example, although the rad value for gamma radiation and alpha radiation may be the same, the RBE value for alpha radiation is about 20 compared to 1 for gamma ra .iation. This, in effect, says that alpha particles cause 20 times as much damage to tissues as the same rate of gamma radiation.

	RBE
X	1
Gamma	1
Beta	1
Thermal neutron	3
Proton	9
Fast neutron	10
Alpha	20

Questions

1. An alpha particle physically resembles:

   a. an electron with a positive charge,

   b. high frequency X-rays,

   c. a helium nucleus, or

   d. a uranium nucleus.

2. Radioactive half-life is defined as:

   a. one-half the lifetime of a given amount of radioactive material,
   b. the time required for a given amount of radioactive material to decompose so that only one-half remains,
   c. the spontaneous emission of charged particles, or
   d. the number of atoms of a given amount of radioactive material that disintegrate per second.

3. The exposure of a living organism to ionizing radiation will cause:

   a. the organism to become radioactive,
   b. a short period of increased growth in the organism followed by injury and possible death,
   c. biological damage to the more radiosensitive tissues of the organism, or
   d. biological damage to the organism.

4. The midlethal dose of acute total body radiation exposure to man is:

   a. 200 r
   b. 450 r
   c. 600 r or
   d. 800 r

5. The radiation-absorbed dose (rad) is a unit of measurement based on the absorption of:

   a. 83 ergs of energy of X- or gamma radiation in air,
   b. 100 ergs of energy of all types of radiation in any material, or
   c. the amount of energy produced by 37 billion atoms disintegrating per second.

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THEORY OF NUCLEAR EXPLOSIONS[1/]

In general, an explosion is the release of a large amount of energy in a restricted space and time. This release of energy is accompanied by high temperatures and the hot gases push out the surrounding medium — whether it is air, earth, or water — to create an outward moving pressure which constitutes the blast or shock of an explosion. In this respect, a nuclear weapon is similar to the more conventional high-explosive type of weapon.

However, there are some basic differences between nuclear and high-explosive weapons as well as the many similarities. These differences may be listed as:

(1) Fuels - High-explosive weapons are commonly composed of TNT. Nuclear weapons are usually composed of uranium, plutonium, or hydrogen.

(2) Reaction - Energy is released from high-explosive weapons by a <u>chemical</u> rearrangement of the <u>molecules</u> of the fuel. Energy is released from nuclear weapons by a <u>physical</u> change of the <u>atoms</u> of the fuel.

(3) Effects - High-explosive weapons release energy by means of heat, light, and blast. Nuclear weapons release energy by means of heat, light, blast and <u>lethal</u> radiation.

(4) Destruction - High explosives have a built-in limit to the destructiveness of the weapon because of the physical impossibility of providing sufficient fuel for ''nuclear size'' explosions. There is no practical limit to the size of a thermonuclear weapon.

In addition to the above, nuclear weapons leave a residual deposit of radioactive fission products, or radioactive fallout, on surrounding areas that can be lethal over an extended period of time.

Nuclear Reactions

Nuclear weapons are much more forceful than conventional weapons because the binding force, or energy, of the nucleus of an atom is much greater than the binding force between the atoms in a molecule of TNT. Consequently, when the splitting of a nucleus occurs, much more energy is released than when the atoms of a conventional fuel are rearranged, when equal masses are considered.

The basic requirement for energy release is that the total mass of the fuel be greater than the total mass of the end products. There is a definite relationship between mass and energy, and when a decrease in mass occurs, as in a nuclear reaction, there is a certain amount of energy released in proportion to the decrease in mass. This bears out the theory Albert Einstein developed many years ago. It is now accepted as a law of nature that whenever a change occurs from constituents held

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1/ Prepared by James D. Lane, Meat Inspection Division, Agricultural Research Service, U. S. Department of Agriculture.

together by weaker forces into constituents held together by stronger forces, it is accompanied by the release of energy and a corresponding decrease in mass.

In addition, another requirement of a nuclear weapon is that the reaction must be able to sustain itself. In nuclear physics, this is called a chain reaction. Without such a chain reaction, large amounts of energy cannot be produced. The two types of nuclear reactions that can satisfy these conditions and produce a large amount of energy in a short time are called fission and fusion.

Fission

Uranium and plutonium, two fissionable fuels, meet the two requirements of a nuclear reaction. In fission, there is a conversion of mass to energy by the breakdown of unstable heavy atoms into more stable atoms of less weight. Also, a sufficient amount of either of these fuels will sustain a chain reaction. When a neutron enters the nucleus of a fissionable atom, it causes the nucleus to split into two or three parts. This is accompanied by the release of tremendous amounts of energy. The smaller (or lighter) atoms that result are called "fission products." The complete fission of 1 pound of uranium or plutonium can produce as much energy as the explosion of 9,000 tons of TNT.

Uranium and plutonium are two of the heaviest elements known, and both are unstable. Being unstable, they are slightly radioactive and emit alpha particles until they are finally transformed into a stable isotope of lead. Consequently, when an unstable atom such as uranium is exposed to a neutron bombardment, the uranium nucleus absorbs a neutron and, like an oversize balloon, bursts into two or more smaller pieces. This can be graphically shown as:

Uranium + neutron $\longrightarrow$ fission products + neutrons + energy

Chemically written, the same reaction will be:

$$_{92}U^{235} + {}_{0}n^{1} \longrightarrow 2\ FP + 3\,{}_{0}n^{1} + 200\ Mev\ E$$

We see from this formula that only 1 neutron initiates fission; however, 3 neutrons more are released by the reaction. Thus, 1 neutron releases 3 others, and each of these releases 3 more, etc., and a chain reaction results. In addition to the fission products produced and neutrons released, 200 million electron volts of energy are produced by each fission of 1 uranium atom.

Figure 14 shows the typical isotopes formed in the fission of uranium 235. The vertical axis represented in logarithmic scale indicates that the fission products vary in percent yield from one 100,000th of 1 percent to 6-1/2 percent of the total yield. On the horizontal scale, it is seen that the atomic weight or mass of the isotopes varies between 72 and 162. The atomic number of the isotopes, represented by the letter Z, varies between 30 (zinc) and 64 (gadolinium). All of these radioactive isotopes emit beta particles and many also emit gamma rays. The yield in fission products of uranium 238 and of plutonium is very similar to that shown here for uranium 235.

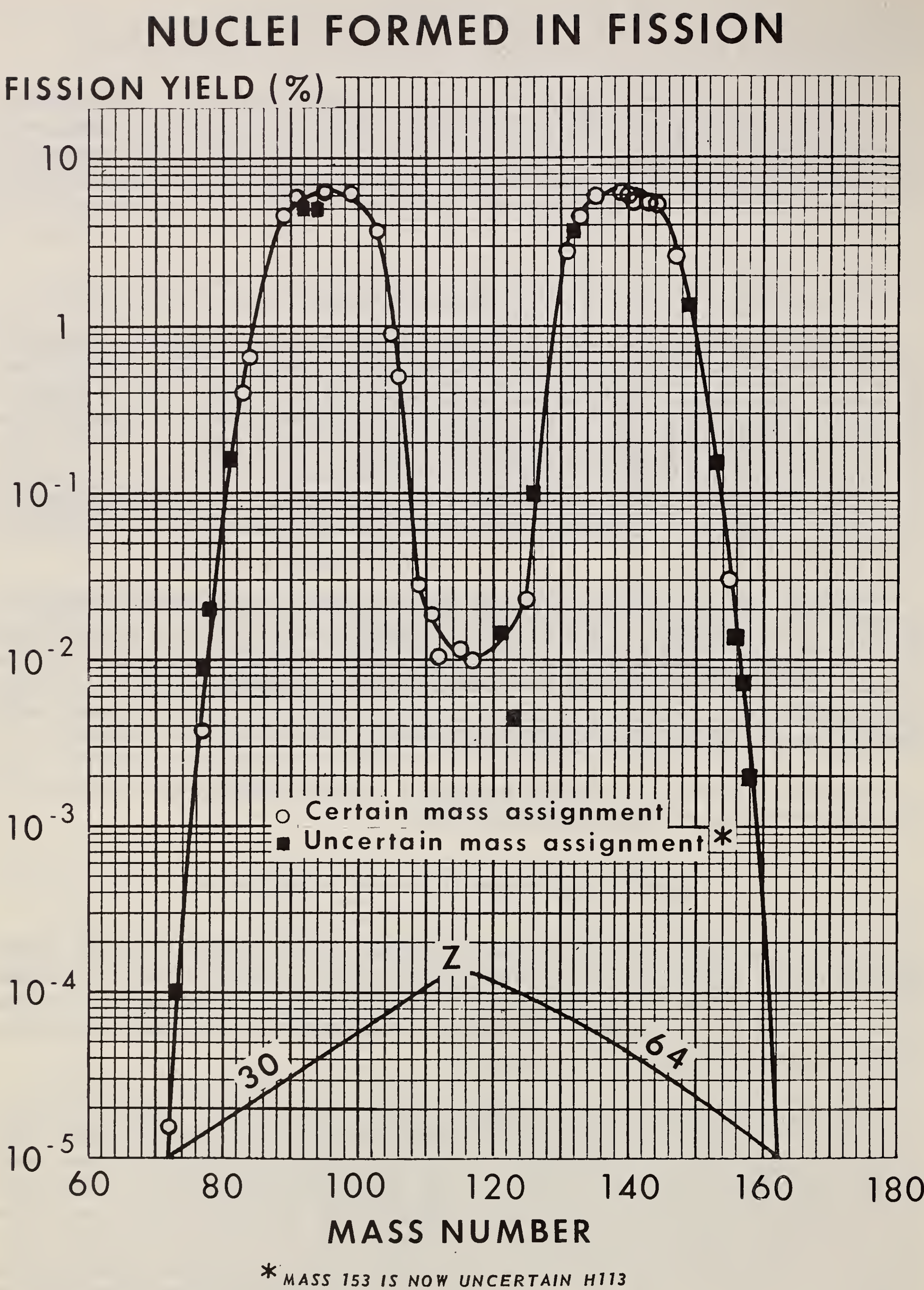

Figure 14.—Nuclei formed in fission.

Chain Reaction

Although 3 neutrons are usually produced by the fission of an atom of U-235, as a rule not all of these neutrons are available for causing more fissions. Often at least one of them escapes or does not immediately cause a fission. However, for the sake of simplicity, we can assume that 2 of the released neutrons will cause 2 other atoms to fission, and these 4 more, then 8, 16, 32, and so on. If this does happen, in less than 90 generations enough neutrons will be produced to cause the fission of over 100 pounds of uranium — resulting in the liberation of energy equivalent to a million tons (1 MT or 1 megaton) of TNT.

Each of these fission generations takes only about 1 hundred-millionth of a second to occur so that 90 generations can be obtained in less than a millionth of a second. This nearly instantaneous release of neutrons accompanied by the release of tremendous amounts of energy is the basic principle of the nuclear fission bomb.

Critical Size

Since some of the neutrons produced in the fission of uranium (or plutonium) are lost by escape, it is possible that more will escape than will be captured and a chain reaction will not be self-sustaining. It is necessary, therefore, to minimize the loss of neutrons in order to achieve a nuclear explosion.

The escape of neutrons is at the surface of the uranium mass or by absorption of neutrons by impurities in the uranium. The problems then are (1) to reduce the impurity content and (2) to design a weapon with maximum mass and minimum surface area. The first problem is met by careful processing controls and the second problem by increasing the ratio of the volume to the surface area. A round compact sphere has been found to be the best shape for a nuclear weapon. Too, it has been found that the larger the sphere, the lower the relative loss of neutrons there will be. And when the sphere reaches the size sufficient to insure a chain reaction, it is referred to as a "critical mass" of the fissionable material.

For a nuclear explosion to take place, the weapon must thus contain a sufficient amount of uranium (or plutonium) for it to exceed the critical mass under the existing circumstances. Also, the critical mass depends on the shape of the material, the composition, and the presence of impurities which can remove neutrons in nonfission reactions. By surrounding the material with a "reflector" that turns many of the escaping neutrons back into the mass, the neutron loss is diminished and the critical mass can be decreased.

Critical Mass

To prevent the formation of a critical mass before a nuclear explosion is wanted, the weapon must be so designed that the uranium (or plutonium) is in subcritical masses before use. In order to produce an explosion, it must be quickly converted into a supercritical mass. If this is not done very rapidly and held in a supercritical form for a brief instant of time, a critical mass will result which will lose enough neutrons so that the fuel will melt, or a reduced amount of fission will occur.

To accomplish a full nuclear explosion, two systems of rapid conversion from a subcritical to supercritical mass are used. One is by placing two subcritical masses at opposite ends of a gun barrel device. A high explosive is then used to blow one subcritical piece from the breech end of the gun into the other subcritical piece held firmly in the muzzle end. The other method used is based on the information that a subcritical mass can become critical or supercritical when strongly compressed. In a weapon this is done by a spherical arrangement of specially shaped high explosives around a subcritical ball of fissionable material. When the high explosive is set off, an inwardly directed "implosion" wave is produced that compresses the sphere of uranium into a supercritical mass and a nuclear explosion results.

Fission Products

Many different fission fragments result from the fission of uranium or plutonium. All of the 60 to 80 fragments that can result are radioactive and emit negatively charged beta particles during their decay. Also, this radioactive decay is often accompanied by gamma radiation which serves to carry off excess energy.

As the result of the beta emission, the fragment is changed to another element, which is usually radioactive, also. On the average, there are three stages of radioactivity for each fission product before a stable (non-radioactive) nucleus is formed. Since fission can occur in so many different ways, the fission product mixture becomes very complex and may contain somthing like 200 or more different isotopes of various elements.

Each radioactive change of an element — with the accompanying emission of a beta particle and often a gamma ray — takes place at a specific rate for that element. This rate is known as the "half-life" of that element. In other words, each radioactive isotope of an element has its own specific decay rate and this varies from a fraction of a second to thousands of years. Although we know the decay rate for each isotope, the mixture formed after a nuclear explosion is so complex that it is not possible to represent the decay as a whole in terms of half-life. Nevertheless, it is possible to calculate the rate of decay of mixed fission products fairly accurately by means of a simple formula. This formula states that for every sevenfold increase in time, the radioactivity of the fission products decreases tenfold. Thus, if at 1 hour following the explosion the activity is taken as 100 r, at 7 hours after the explosion the activity will have decreased to 10 r. Within about 2 days the activity will have decreased to 1 r.

Alpha Activity

In addition to the beta particle and gamma ray activity of the fission products, some alpha particle activity is often found near the site of the explosion. This activity is from the uranium or plutonium that did not completely fission or was produced in the explosion and this fuel residue settles back to earth with the fission products. Although the alpha particles emitted by uranium or plutonium are not generally considered an external radiation hazard, they may cause serious effects if taken into the body through skin wounds or by ingestion or inhalation.

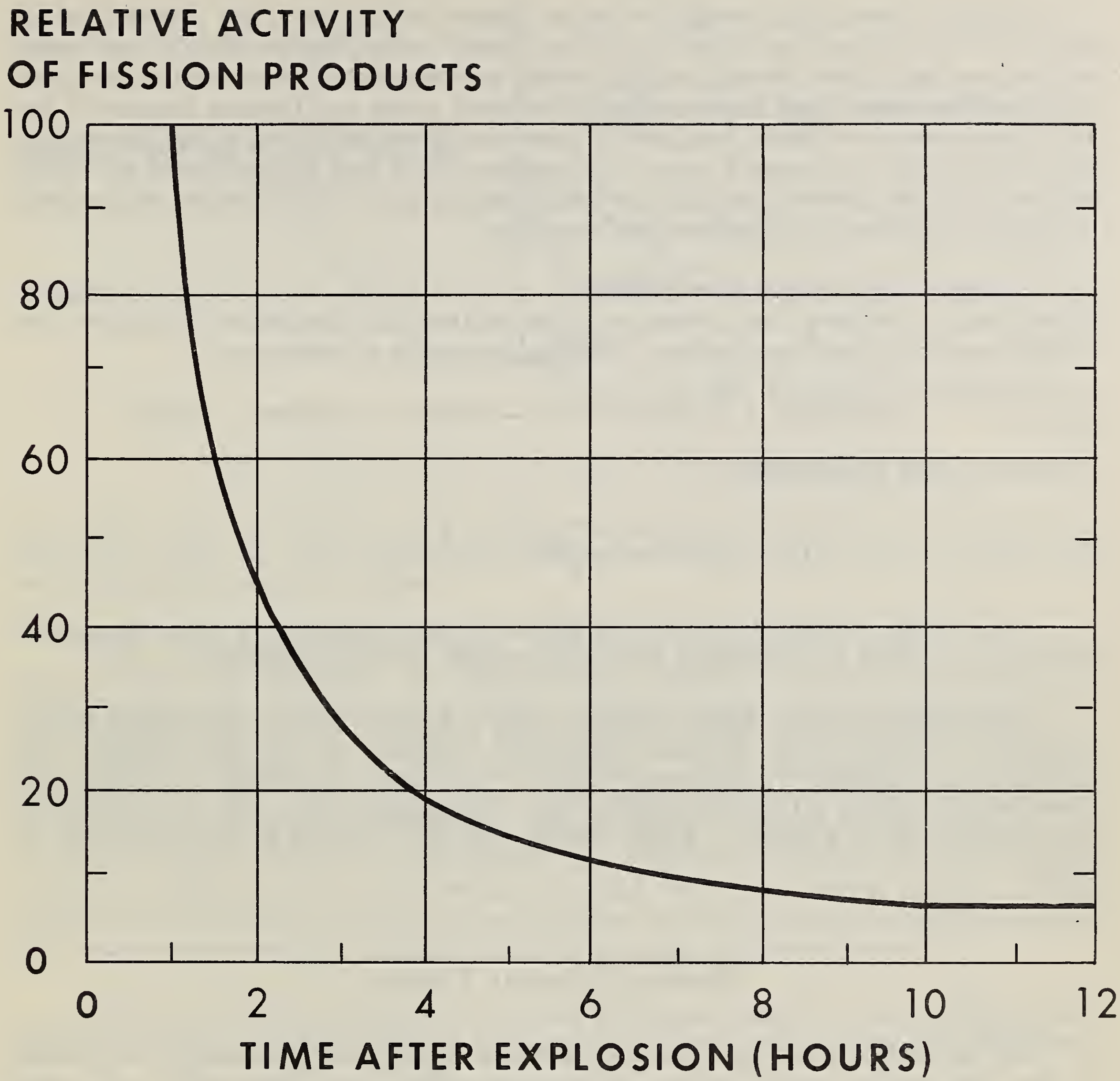

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Figure 15.—Rate of decay of fission products after a nuclear explosion.

Neutrons

Many neutrons are produced during an atomic explosion. Those not absorbed by uranium or plutonium nuclei in the chain reaction process are usually absorbed by the air or vaporized bits of the weapon casing, or they may be absorbed by the particles of soil drawn into the atomic cloud. As a result, the air or other material may become radioactive and increase the initial radiation and the radioactivity of the fallout.

Fusion

Nuclear fusion, long thought to be the source of energy of our own sun and the stars, is the coalescing of two or more atomic nuclei. Fusion occurs when nuclei of various light (low atomic weight) atoms are subjected to tremendous energies, such as extremely high temperatures. Hydrogen being the lightest element, it has been found that the fusion reaction is most easily accomplished by subjecting isotopes of hydrogen to extreme temperatures. Since very high temperatures are easily obtained by the fission reaction, the resulting fusion of hydrogen in the presence of fission is termed a "thermonuclear reaction."

The hydrogen isotopes most commonly used in fusion reactions are hydrogen-2 (deuterium) containing one proton and one neutron, and hydrogen-3 (tritium) containing one proton and two neutrons. This reaction may be shown as:

$$\text{Deuterium} + \text{Tritium} \longrightarrow \text{Helium} + \text{neutron} + \text{energy}$$

Chemically this is shown as:

$$_1H^2 + {}_1H^3 \longrightarrow {}_2He^4 + {}_0n^1 + E$$

The energy released by this reaction is approximately 4 times the amount of energy released by the fission of an equal weight of uranium-235.

This triggering of a fusion reaction with a fission reaction to produce a thermonuclear reaction also releases additional neutrons during the explosion. The neutrons are captured by additional atoms of uranium or plutonium to insure more complete fission of all the fissionable fuel. Consequently this type of reaction has been referred to as a fission - fusion fission reaction, or more popularly as a "3-F" bomb.

Hazards of Nuclear Weapons

The hazards of nuclear weapons fall into three general categories according to how the energy of the weapon is dissipated. These are <u>blast effect</u>, accounting for about 50 percent of the energy of the explosion; <u>thermal effect</u>, accounting for about 35 percent of the energy; and <u>ionizing radiation</u>, the remaining 15 percent of explosion energy. The ionizing radiation may be further subdivided to give 5 percent of the total as initial radiation, and the remaining 10 percent as residual radiation resulting from fallout.

Blast Effect

Blast travels at about the speed of sound and results from the rapid expansion of the super-heated gases in the fireball of the bomb. The expanding gases exert extremely high pressure and push out the surrounding medium (of air, water, or earth)

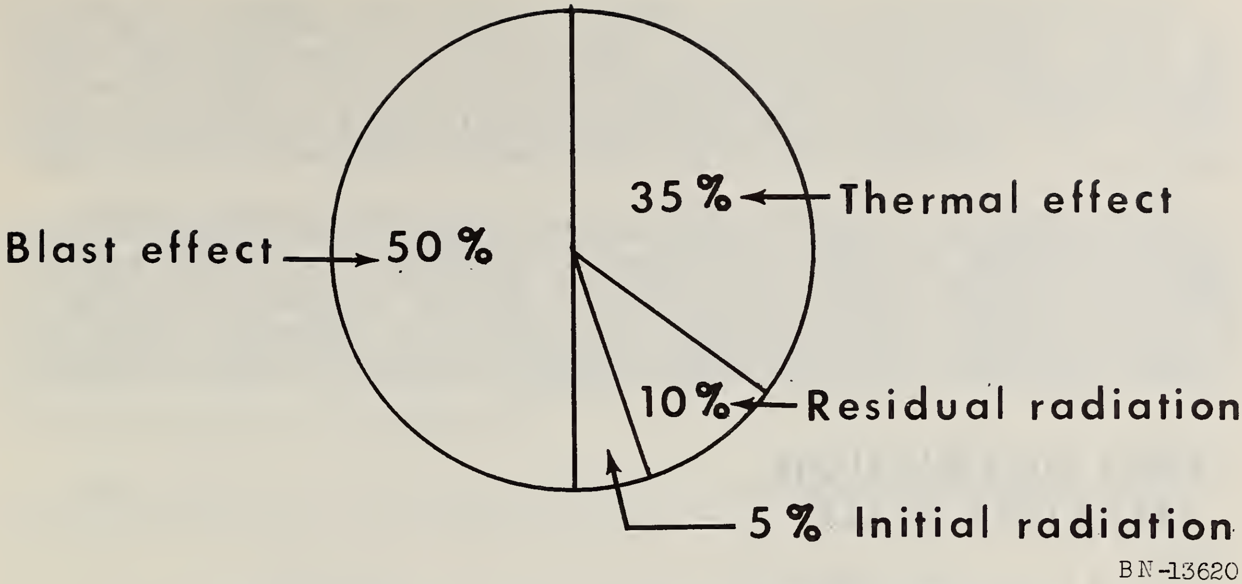

Figure 16.-Distribution of energy from nuclear explosion.

to create a wave of pressure that travels outward at a high velocity in all directions from the center of explosion. This accounts for most of the material damage from an air burst of a nuclear weapon.

Blast affects buildings and other objects by overpressure (that is, the excess over atmospheric pressure), by strong winds created by the blast and by negative overpressure (the dropping of pressure below the atmospheric surroundings). As the initial overpressure strikes a structure the difference in air pressure acting on separate surfaces of the structure produce a force of destruction. This is accompanied by very high winds (over 1,000 miles per hour in some instances) and is followed in a short time by the negative phase of overpressure (or suction) of a lesser degree. Since few structures can withstand an overpressure of one-half pound per square inch or more without damage, the area close to the point of detonation usually suffers extremely heavy damage. Overpressures as high as 72 pounds per square inch have been recorded from large-scale nuclear weapons.

The extent of blast damage is a function of weapon size. The blast damage zones shown as miles in radius from a 20 megaton weapon are approximately as follows:

Complete building destruction. . . .	5 miles
Heavy building damage	10 miles
Moderate building damage.	15 miles
Light building damage	20 miles

Thermal Effect

The thermal effects of nuclear weapons are a result of the intense heat from the fireball being propagated outward in all directions in the form of infrared rays, visible light, and ultraviolet rays. Thermal energy being electromagnetic energy, travels with the speed of light and this radiation continues to be given off as the fireball builds up. Thermal radiation may be emitted for a period of 10 seconds or longer in the larger weapons.

Figure 17 shows that thermal radiation from a nuclear explosion is emitted in two pulses. The initial pulse is almost instantaneous and reaches very high temperatures and then drops very low again before beginning the second rise followed by a slower falloff of intensity. The initial pulse may last for a period varying from a fraction of a second to several seconds depending upon the size of the weapon.

The fireball of a nuclear weapon may attain a temperature of several million degrees and from a radiation standpoint it resembles the sun in many respects. And since thermal radiation travels with the speed of light, the time elapsing between its emission from the ball of fire and its arrival at a target a few miles away is quite insignificant. However, these radiations, like the sun's rays, are attenuated

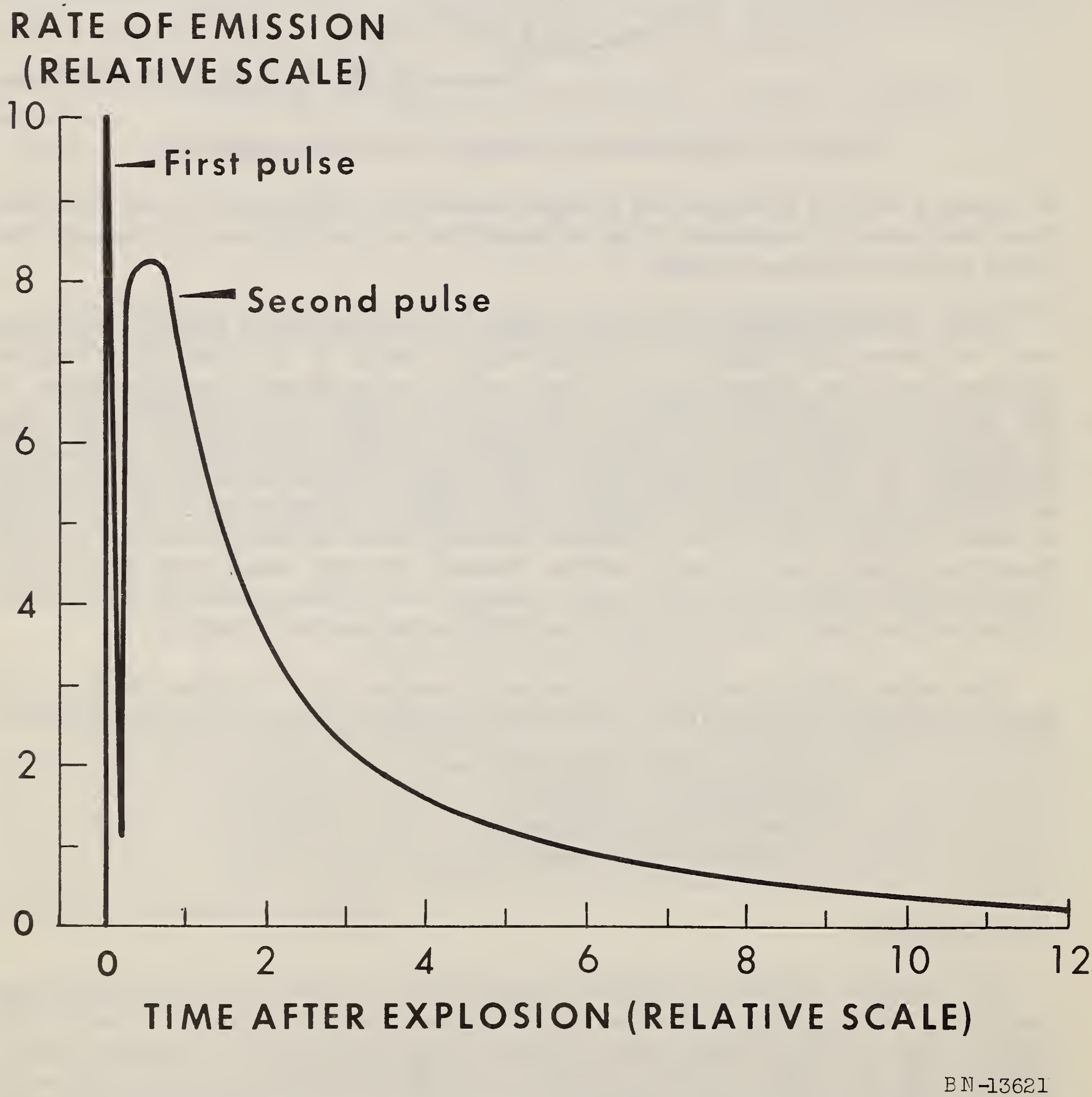

Figure 17.—Emission of thermal radiation.

as they pass through air so that the amount of thermal radiation that will reach a given point depends on the distance from the burst and the condition of the intervening atmosphere. Just as with sunlight, much of the ultraviolet radiation is absorbed in the air, so that most of the thermal radiation received at some distance from the fireball lies in visible and infrared regions of the spectrum.

Although blast is responsible for most of the damage from a nuclear explosion, thermal radiation will contribute to the over-all damage by igniting combustible materials, such as dried leaves and newspapers, and thus starting fires in buildings or forests. These fires may then spread rapidly among the debris of a blast. In addition, thermal radiation is capable of causing skin burns on exposed individuals at distances from the nuclear explosion where the effects of blast and of initial nuclear radiation are not significant.

Shown below are the types of burns that could result in an exposed person at various distances from a 20 megaton nuclear weapon:

28 miles . . . . 3rd degree burn
32 miles . . . . 2nd degree burn
44 miles . . . . 1st degree burn

Initial Radiation

Initial nuclear radiation may be defined as those radiations emitted during 1 minute following the instant of a nuclear blast. Such radiations are composed of neutrons and gamma rays emitted during the actual fission process, radiations from fission products, and radiations from air and other materials made radioactive by neutron capture during and immediately following the explosion. Since the range of alpha and beta particles is relatively short, the effective initial radiation can be considered as only gamma rays and neutrons. Both gamma rays and neutrons can penetrate considerable distances in air and they both produce harmful effects on living organisms. So it is the highly injurious nature of these radiations, combined with their high intensity and long range, that makes them such an important aspect of nuclear explosions.

Fission products are extremely radioactive immediately following a nuclear explosion and contribute heavily to the high intensity of initial radiation. This is possible within 1 minute following the explosion because the fission products have not as yet had time to rise with the atomic cloud. Consequently, during this period the rays emitted can affect a large area of the ground surface near the point of detonation. The neutrons produced by the fission process are also very energetic and those not captured by nuclei in the region of the fireball may travel up to 2 miles from the point of burst. Anywhere within this 2-mile range the neutrons can cause induced radiation in any material they contact or cause severe biological damage to living organisms.

Shielding from initial radiation when close to a bomb burst is a problem. As an example: A fairly light shield will provide protection from thermal radiation at 1 mile from a one megaton bomb. Yet the initial nuclear radiation would probably prove fatal to 50 percent of the people even though sheltered by 24 inches of concrete.

Shown below is the initial gamma radiation dosage in roentgens at various distances from a 20 megaton explosion:

2.3 miles	1,000 r
2.6 miles	300 r
3.2 miles	30 r

Residual Radiation

The residual nuclear radiation is defined as that emitted after 1 minute from the instant of a bomb explosion. It is composed of the fission product emissions and, to a lesser extent, emissions from the uranium and plutonium that have escaped fission. In addition, some radioactive isotopes are formed by neutron capture by bomb casing fragments and by atoms in the air and soil or water drawn into the bomb cloud.

About 1-3/4 ounces of fission products are formed for each kiloton (or 110 pounds per megaton) of fission energy produced. It has been calculated that this 1-3/4 ounces of fission products is comparable in radioactivity to 100,000 tons of radium. So it is clearly seen that the amount of radioactivity produced from a megaton sized weapon is enormous. Fortunately the radioactivity decreases rapidly with time; but, even several days after fallout from a large weapon has reached the ground, the intensity is still high.

Since fallout and its accompanying radiation are discussed in greater detail elsewhere in this publication, fuller explanation will not be attempted here. However, to gain an insight into a typical fallout intensity pattern from a megaton size weapon, the following fallout intensity readings have been made from a 12-15 megaton weapon detonated on the surface of a small island in the Pacific in 1954. The fallout area was a cigar-shaped zone about 220 miles long and 20 to 40 miles wide. The dosage given is that which would be encountered during the first 36 hours following the explosion.

10 miles downwind.	5,000 r
100 miles downwind.	2,300 r
125 miles downwind.	1,000 r
140 miles downwind.	800 r
220 miles downwind.	400 r

A dosage of 400 r is considered lethal to 30-40 percent of the humans exposed to this amount of radiation over a 36-hour period. Seven hundred roentgens would be considered lethal to 100 percent of the population exposed. (See Fig. 18 - Dose Rate Contours, and Fig. 19 - Total Dose Contours.)

Types of Burst

Nuclear weapons may be detonated under various conditions to obtain different types of burst. The effects of shock or blast and thermal and nuclear radiations

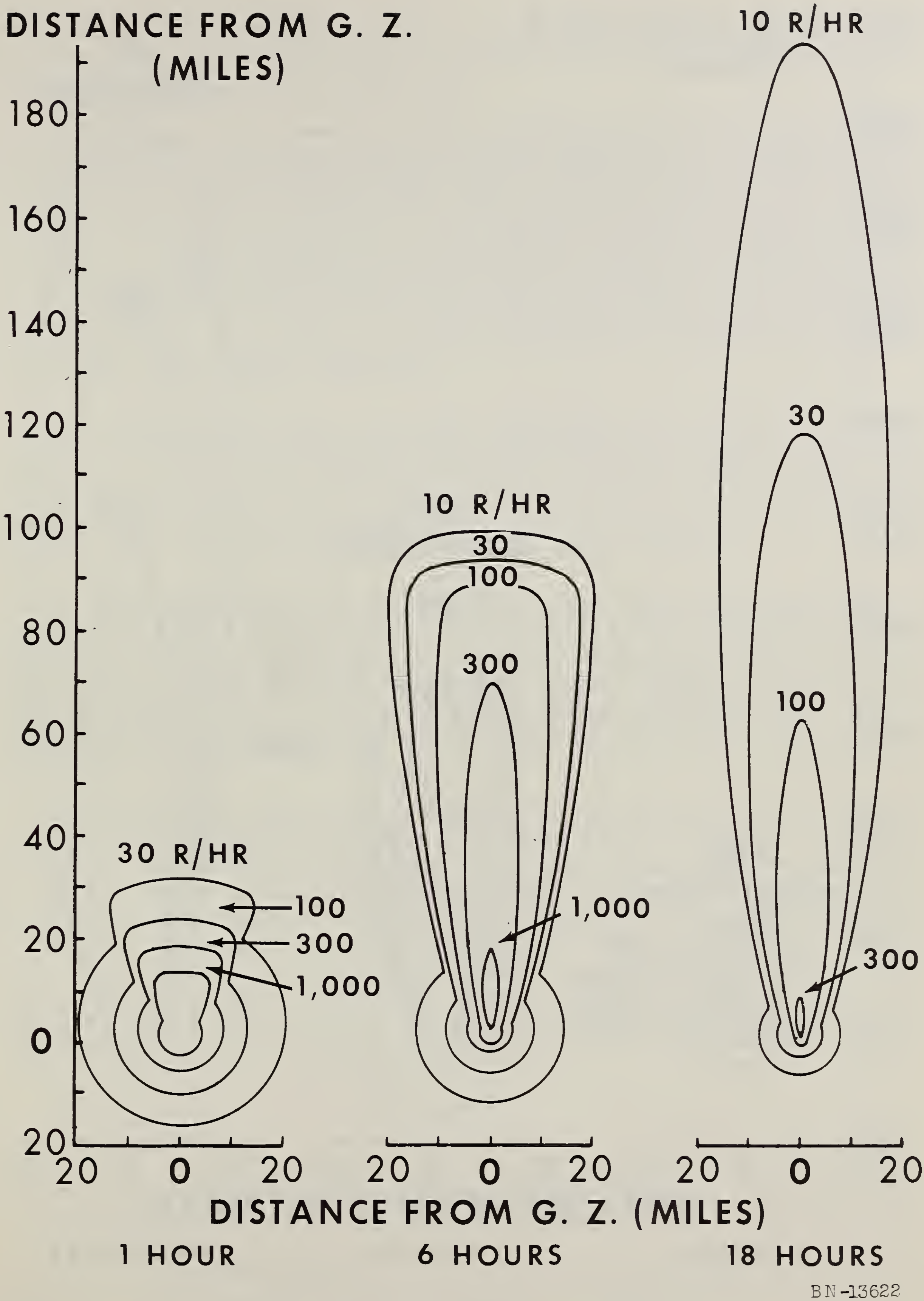

Figure 18.—Dose rate contours.

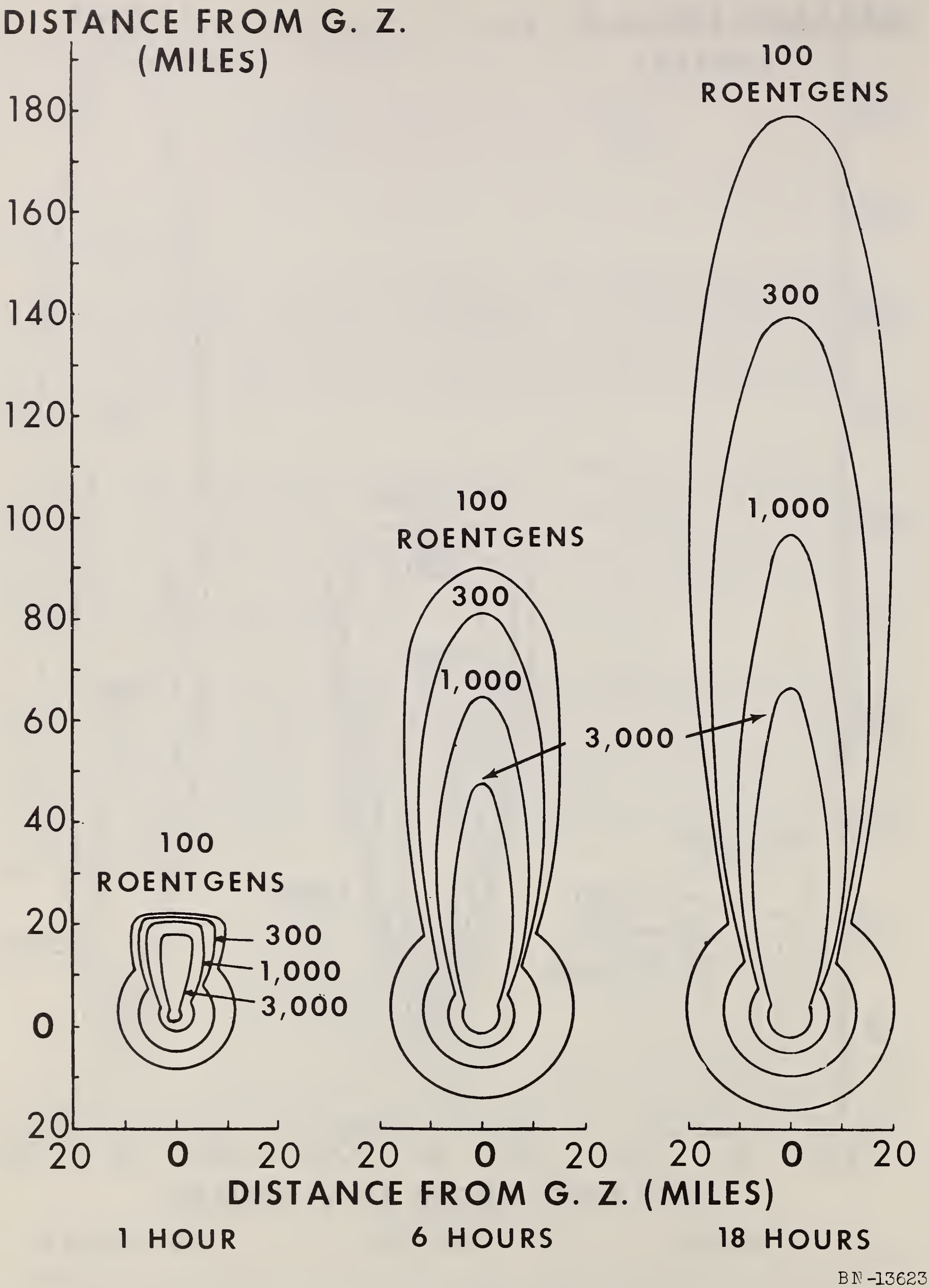

Figure 19.—Total dose contours.

vary with the location of the detonation in relationship to the surface of the earth. The four main types of burst may be called (1) air burst, (2) underwater burst, (3) underground burst, and (4) surface burst.

An air burst is one in which the bomb is exploded in the air over land or water at such a height that the fireball does not touch the surface. For a 1 megaton weapon, this must be at nearly 3,000 feet altitude since the fireball extends nearly 1.1 miles across at its maximum brilliance. This type of burst exposes the maximum area to the effects of blast and thermal and nuclear radiations but produces the least amount of fallout. A 1 megaton weapon under such conditions would cause moderately severe burns of exposed skin as far away as 12 miles on a fairly clear day. The warmth may be felt a distance of 75 miles. A person 1 mile from such a detonation would need the protection of 1 foot of steel or 4 feet of concrete to be relatively safe from the effects of the initial nuclear radiations.

In an underwater burst, most of the blast energy of the explosion appears as underwater shock, but a certain proportion, depending on the depth of the burst, escapes and produces airblast. Much of the thermal and initial radiation energy would be absorbed by the water and dissipated as heat in the water. However, the residual radiation would be of great consequence, since large quantities of water and mist in the area would be contaminated with radioactive fission products.

An underground burst acts much as an underwater burst if the depth is not so deep that the fireball is confined within the earth. In a shallow underground burst, much of the blast is converted to a shock wave in the earth and the thermal and initial nuclear radiations would be similarly largely confined to the immediate area of the burst. However, the fallout from a shallow underground burst would be extremely heavy in the area of the detonation, but relatively light at a greater distance away.

In a surface burst the device is detonated on the actual surface of the land or water, or it is detonated at a height such as the fireball touches the surface. On land, a crater is formed by the violence of the explosion and large amounts of soil are carried aloft to create heavy residual radiation as fallout. Over water, a base surge consisting of radioactive mist and water droplets extends as a moving mass outward from the point of burst. The mist produced also can be carried many miles by the wind. The energy of the explosion causes both airblast and water or ground shock. The thermal and initial nuclear radiations will be more intense close to the point of detonation, but usually the effects drop off rapidly with increasing distance from the burst. Residual radiation in fallout, whether over land or water, is heavy.

Questions

1. Gamma rays emitted during megaton-size nuclear detonations may penetrate air up to a distance of:

   a. one-half mile,
   b. 3 miles,
   c. 6 miles, or
   d. 10 miles.

2. Initial ionizing radiation produced from the detonation of a typical megaton-sized nuclear weapon contains;

   a. free neutrons and gamma rays,

   b. beta particles and free neutrons,

   c. beta particles, gamma rays, and free neutrons, or

   d. beta particles and gamma rays.

3. Local fallout (falling within 12 hours from time of burst) from a nuclear weapon detonation as a general rule contains radioactive material emitting:

   a. alpha particles, beta particles, and gamma rays,

   b. beta particles and gamma rays,

   c. neutrons, beta particles, and gamma rays, or

   d. neutrons, alpha particles, beta particles, and gamma rays.

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FALLOUT 1/

The term "fallout" is used to describe the radioactive particles produced by a nuclear or thermonuclear detonation when they fall back upon the earth from the upper air. Fallout is composed of fission products, particles of the bomb itself, substances made radioactive by neutrons, and material from the surface of the earth carried aloft by the explosion. The great bulk of this material will undergo radioactive decay before the particles have fallen to the earth. When, however, the detonation is such that the fireball touches the ground, great amounts of earth are drawn into the rapidly rising fireball. Highly radioactive particles result, the coarser of

1/ Prepared by Samuel E. Grove, Meat Inspection Division, Agricultural Research Service, U. S. Department of Agriculture.

which tend to fall rapidly while being carried along by the wind. The cloud created by a thermonuclear explosion rises rapidly to the highest levels of the atmosphere and spreads over hundreds of square miles in the first hours.

The particles carried up into the atmosphere by the detonation are acted upon by gravity and are carried by the winds. The winds vary in both direction and speed from one level to another, so that each particle follows a constantly changing course at changing speeds during its fall. The rate of fall depends on size, shape, and weight of the particles and the characteristics of the air. The stronger the winds in each layer, the farther the particles will be carried in that layer. The higher the altitude at which it begins to fall, the longer it will be carried by the wind and under most conditions (when the winds at different altitudes do not oppose one another) the farther it will travel. Wind data alone, of course, do not indicate the levels of radiation to be expected. Levels depend on such things as altitude of the burst, amount of energy released, nature of the ground surface, height to which the cloud rises, and design of the bomb. These things cannot be known accurately beforehand, which makes it difficult to predict the radiation levels that will result.

The Radioactive Fallout Problem

Recent developments in nuclear weapons have increased the probability that serious amounts of radiation from fallout may be experienced in addition to the blast and thermal effects. Initial radiation (the gamma rays and neutrons released instantaneously with the explosion) produced by a nuclear weapon does not present a serious hazard beyond the area where heat and blast are of greatest concern. However, residual radiation from such a detonation may be expected to affect very large areas for a considerable period of time. Fallout is the phenomenon responsible for the major part of the residual radiation hazard.

For a considerable distance around the point of detonation, radioactive particles will be distributed upwind and crosswind, as well as downwind. The actual distance to which this close-in contamination will extend depends on the yield of the weapon and may be expected to cover at least the area of light damage. This area will probably be highly radioactive.

Outside the zone of close-in contamination, radioactive fallout can be expected to occur in the direction of the resultant effective wind over an area of many square miles. The radioactive material may or may not be visible but can be detected with radiological monitoring instruments. Falling dust or ash, if visible, will most likely be radioactive.

The intensity of the radiation is very high immediately after the burst, but "decays" or diminishes rapidly. Therefore, since not much time will have elapsed, the particles reaching the ground near the burst will be very highly radioactive, whereas those carried a long distance by the wind will have lost much of their radioactivity before they alight. The fallout material on the ground, of course, continues its radioactive decay. After 24 hours, intensity is about 2 percent of the intensity at 1 hour after the burst. This may still be very dangerous at some points, however.

Relative Energy of Residual Radiation

Radiation emitted from fallout has a lower penetrating power than the initial radiation produced at the time of bomb detonation. Therefore, the effectiveness of a given thickness of shielding will be greater for residual than for initial nuclear radiation.

Probability of Extensive Radiological Contamination

Radiological contamination, although in no sense restricted to high-yield thermonuclear detonations, becomes a matter of major concern when a large weapon of the type used in the 1954 Pacific tests is exploded near the ground. The fallout of radioactive materials from such an explosion may, under certain circumstances, settle over wide areas far removed from the point of detonation.

The areas seriously affected by heat and blast of a thermonuclear weapon are large, but are small indeed compared to the area of residual radiation hazard produced by fallout. Because of the wide day-to-day variability of the wind direction and speed at different heights, it is impossible to apply a single fallout pattern to all detonations. The area of significant contamination will be largely dependent upon the yield of the bomb. Its location, with regard to ground zero, and its width and length, will be determined by the direction and speed of the wind at various heights and distances. In general terms, the area will be a modified cigar-shaped area extending "downwind" from the point of burst. It is obvious that dimensions depend upon so many uncertainties that no precise predictions can be made. Realistic assumptions, however, based on experimental data from the Pacific Test Site, provide an adequate basis for planning for operational preparedness.

The thermonuclear bomb fired at the Bikini Atoll on March 1, 1954, resulted in an area of contamination (100 r or more cumulative dose, 24 to 48 hours after the detonation) of nearly 14,000 square miles, with the heaviest concentration falling on the central portion of the ellipse extending some distance from the point of burst. Some of the early fallout from this explosion occurred in the form of a fine dust, which looked like snow. On the inhabited islands about 170 miles downwind, the fallout began about 8 hours after the detonation and continued for several hours.

On the basis of gamma dose radiation effect, the March 1, 1954, explosion heavily contaminated an area extending approximately 160 miles downwind and up to 40 miles in width. On the same basis, and with the assumption of no shelter or other protective measures, it has been estimated that in a downwind belt about 140 miles long and up to 20 miles wide the residual radiation would have been fatal to nearly all persons remaining there 24 to 48 hours, and that at about 190 miles the radiation would have been fatal to about 5 to 10 percent of the people. Thus, about 7,000 square miles of territory would have been so severely contaminated that survival would depend on prompt protective measures. Beyond a point about 220 miles distant, it is unlikely that any deaths would have resulted from radiation.

Questions

1. Fallout has a (lower, higher) penetrating power than radiation produced when the bomb detonates.

2. In a nuclear detonation, in which the fireball touches the ground, soil particles will be carried into the (lower, higher) levels of the atmosphere, and the particles will generally be of (small, large) size.

References

(1) Technical Bulletins TB 11-19, 11-21, and 19-1. Office of Civil and Defense Mobilization.

BIOLOGICAL EFFECTS OF RADIATION[1/]

The first practical use of ionizing radiation was Wilhelm Roentgen's picturing of the bones of the hand and arm by X-rays in 1895. At that time, no one knew what ionizing radiations might do to living bodies but one effect was soon evident. By the latter part of January 1896, Mr. E. H. Grubbe, an experimenter and manufacturer of X-ray tubes, reported a reddening or erythema of the skin of his hands from their exposure to X-rays during his study of the fluorescence of chemical compounds. This is believed to be the first recorded instance of injury caused by ionizing radiations.

Within a few years, physiologists reported that radiation produced changes in the blood forming organs and the reproductive tissues. By the early 1920's, with a number of industrial and medical uses for radiation developing, scientists had recognized that too much radiation exposure may cause a full spectrum of acute, delayed, and chronic ills, such as tissue necrosis, anemia, decreased vitality, atrophy, and cancer. It is now definite that the wide variety of observed biologic responses to radiation all stem from injury of the individual cells composing tissues. The signs or symptoms of the injury may vary depending on the tissue injured, the amount of injury done, and the repair processes involved. Some effects of radiation, such as the killing of a cancer or the "stimulation" of tissues, benefit the body as a whole. This benefit, however, is a byproduct of primary injury to exposed cells. It may result from killing of radiosensitive cancer cells or it may arise from tissue repair processes stimulated by deliberate radiation injury.

1/ Compiled from a Statement by Bernard F. Trum, Director, Animal Care Center, Harvard Medical School, before the Special Subcommittee on Radiation of the Joint Committee on Atomic Energy, and Concepts of Radiological Health, Public Health Service, U.S. Department of Health, Education, and Welfare, January 1954.

So far as we know, there are several possible results following exposure of living cells to radiation. The cell may be killed outright. It may be crippled, either permanently or transiently. Or it may merely have non-essential molecules ionized and, therefore, actually not be harmed at all by the radiation. (See Fig. 20 - Diagram of Irradiated Tissue.) Symptoms of radiation injury (skin erythema, radiation sickness, decreased fertility) appear in an individual only after a sufficient number of his cells have been injured or killed. Unless the exposure has been sufficient to cause skin erythema, there may be no immediate external warning that a sublethal or even a minimum lethal dose of radiation has been received. Some changes appear early. Others may be seen only after prolonged latent periods. Evidence of injury from minimal doses of radiation may not show up for months or even years.

The recognizable changes produced in cells by radiation are of many sorts. They include changes in permeability of the cell membrane, changes in the staining characteristics of cells, changes in viscosity of the protoplasm, changes in chromosomes, swelling of cellular components, production of abnormal cell divisions, distortion of cell structure, and many more obscure but measurable changes. (See Fig. 21 - Effects of Radiation on Cells.)

Each of the human body's many different tissues responds differently to radiation exposure. The responses, in general, are a summation of the responses of the various cells and cell types composing the specific tissue.

Rapidly growing or metabolizing tissues are usually more sensitive to radiation than are quiescent tissues. Lymphocytic tissues (lymph, nodes, tonsils) are more easily affected than are muscle or nerve tissues. Tissue cells in an organ are more easily injured by radiation than tissue cells grown in a culture.

Various tissues so greatly differ in reaction to radiation absorption that it is possible to classify them, in a loose fashion, according to the doses of radiation they will successfully withstand, i.e., injury, death, etc. Any such classification is empirical and, since it disregards important variables other than dosage, is far from exact. Various authors place some of the tissues in a slightly different order of radiosensitivity. However, the principle of specific tissue sensitivity is generally accepted. The following list is based on the available data and represents the approximate response of tissues exposed to divided doses of roentgen rays generated at 200 kilovolts.

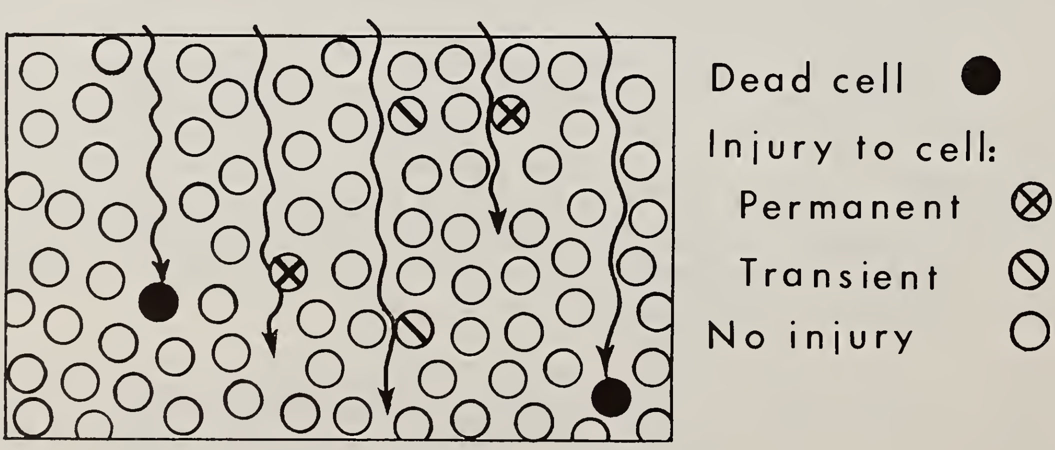

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Figure 20.—Diagram of irradiated tissue.

A. Highly radiosensitive (cells seriously injured or killed by doses of 600 r or less)

Lymphocytes
Bone marrow cells
Sexual cells (testicle and ovary)

B. Moderately radiosensitive (cells seriously injured or killed by doses exceeding 600 r to 3,000 r)

Salivary glands
Epithelium of skin
Endothelium lining blood vessels
Bone (growing)
Epithelium of stomach and intestine
Connective tissue
Elastic tissue

C. Radioresistant (cells show little damage unless dose exceeds 1,000 r)

Kidney
Liver
Thyroid, pancreas, pituitary, adrenal, and parathyroid glands
Bone (mature)
Cartilage
Muscle
Brain and other nervous tissue

Tissues injured by radiation show changes in their individual cells, in the blood vessels supplying them, and in their intercellular material. Changes in the blood vessels play a most important part in the total tissue response. In moderately severe radiation injury, these changes appear early. They range from simple thrombosis (clotting of blood within the vessel) to swelling and overgrowth of the membrane lining the vessel. In the more chronic stages, the blood vessels become narrow, tortuous, and partly or completely blocked. Such changes progress over the years. Tissue changes caused by the resulting decrease in blood supply may be profound. Alteration of the material normally found between the tissue cells may vary from slight visible changes to necrosis. Connective tissue fibers separate, swell, and degenerate.

The recovery of a tissue showing any specific radiation effect is dependent upon the ability of the individual cells composing it to recover and reproduce. This in turn depends upon the dose of radiation absorbed and the types of cells present. The blood-forming organs, the skin, the membranes lining body cavities, and the secreting glands may regenerate completely and resume their normal functions. Muscle, brain, and portions of the kidney and eye cannot regenerate; repair of them results only in scar formation. Even those tissues that can regenerate may fail to respond after repeated ionization and so cause conditions such as nonhealing ulcers or aplastic anemia. Also, repeated regeneration may produce cancerous conditions: epitheliomata, fibrosarcomata, or leukemia. These changes have all been observed in animals

following radiation exposures at levels corresponding to doses only slightly above the accepted safe limits for man. <u>There are no constant clinical symptoms which can be relied upon to warn of latent radiation injury before the late changes become manifest</u>.

The cattle of Alamogordo were the first observed casualties of fallout from nuclear war and their beta burns the first lesions. The first major public health problem from industrial use of nuclear energy, the accident at Windscale, was important because authorities wished to prevent the contamination of the public through the milk of the dairy cow.

Effects are produced when ionizing radiation is absorbed. A quantity of radiation of specific quality produces similar effects regardless of the source of radiation. Therefore derived from field tests, exposure to Co-60, contacts with P-32 plaques, or the ingestion of Sr-90 are equally useful in describing those which can be expected from nuclear warfare.

All domestic animals have a similar response to total body irradiation (Table 2). Few if any die after exposure to 250 r and few survive an acute dose as high as 1000 r. Slower dose rates or fractionated doses are tolerated better than faster delivered acute doses (Tables 3 and 4). Some animals like the swine have a much more rapid recovery rate than others like the burro although there is little difference between the response of the species to an acute exposure. The response of the animal may vary with the quality of radiations, and other things being equal the relative biological effectiveness of X- or gamma radiation is related to the linear energy transfer of the photon (Table 5).

The body size of the animal has little to do with survival although the very young or the very old may be more radiosensitive.

There is no single clinical reaction for irradiation damage in animals. Complete collapse of the burro from an acute exposure in the low lethal range is unique but may be observed in most other animals if high exposure doses are given rapidly. Following an exposure, there are usually several days of good health, which is followed by 4 or 5 days of apathy, then followed by increased irritability, hyperesthesia, decreased food and water intake, and finally death or recovery. Animals usually die or recover within 3 to 4 weeks following exposure to mid-lethal dose of radiation. There is usually a latent period between irradiation and death.

The symptoms most commonly observed following radiation exposure indicate damage primarily to four systems of the body: the nervous system, the digestive system, the blood system, and the respiratory system.

Symptoms suggestive of central nervous system disturbance have been observed during the first 96 hours following irradiation. Encephalitis was manifested by incoordination and loss of equilibrium, staggering gait, falling, circling, pressing forward, and excess salivation. Animals showing these symptoms were usually down within a few hours and seldom recovered.

Symptoms suggestive of damage to the digestive system are anorexia, diarrhea (which may frequently be hemorrhagic), and occasionally vomiting. Cattle usually

TABLE 1.—CONSEQUENCES OF VARIOUS GAMMA RADIATION DOSAGES ON CASUALTY AND MORTALITY RATES IN HUMAN, LIVESTOCK, AND CHICKEN POPULATIONS

Net dosage in roentgens[1/]	Effects[2/] of various net dosages				
	ERD[3/]		96 hour accumulated dose		
	Man		Livestock		Chickens
	C	M	C	M	M
			Percent of total population		
150	0	0	0	0	0
200	0	0	0	0	0
250	100	0	0	0	0
300	100	2	10	0	0
350	100	9	25	0	0
400	100	25	50	8	0
450	100	50	75	20	2
500	100	75	90	32	4
550	100	92	100	50	7
600	100	98	100	75	10
650	100	100	100	91	14
700	100	100	100	100	19
750	100	100	100	100	25
800	100	100	100	100	33
850	100	100	100	100	40
900	100	100	100	100	50
950	100	100	100	100	59
1000	100	100	100	100	68
1050	100	100	100	100	77
1100	100	100	100	100	85
1150	100	100	100	100	93
1200	100	100	100	100	100

1/ Net dose after attenuation for the appropriate amount of shielding applicable to the particular situation being studied.

2/ Measured as casualty (sick or dead = C) or mortality (M) 30 days after beginning of gamma radiation dose accumulation, which hour would be arrival time of the fallout or entry time, depending upon which comes later.

3/ ERD = Effective Residual Dose, a concept currently applicable only to man, and used to determine the effects of gamma radiation upon sickness and death rates. See page 115 for method of calculation of ERD. All casualty estimates by NREC are based on ERD calculations. These effects are taken from OCDM, NDAC (now NREC) TM 70, "Computation Program, Jumbo III," Revised August 1960.

show a good appetite until 3 or 4 days prior to death. Under this condition weight loss is comparatively slight. Diarrhea is usually most common in cattle and sheep. In cattle it can start from the ninth to the twelfth day following irradiation.

Damage to the blood system is indicated by a hemorrhagic syndrome and decrease in cellular elements of the peripheral blood. The hemorrhagic condition

usually begins during the latter part of the second week after exposure. It is also characterized by spontaneous hemorrhaging from scars and old wounds, prolonged bleeding of fresh wounds, and hemorrhaging in excreta and nasal discharge.

Changes in blood cell count occur very early following irradiation. These may include immediate decrease in numbers of circulatory lymphocytes; a lesser and slower reduction and faster recovery of polymorphonuclear leukocytes and erythrocytes; a slower clotting time and impaired clot retraction.

Symptoms of respiratory system damage have been observed in all species of domestic animals. Hemorrhagic nasal discharge is usually observed with hemorrhage in the area of the lateral masses of ethmoid bone in sheep and the frontal sinus in cattle. Occasionally the nasal cavities of sheep are plugged with clotted blood making it necessary for the animal to breathe through its mouth. Increased respiration with associated edema, emphysema, hemorrhage, and infection of the lungs are observed.

Hereford bulls exposed to single doses of Co^{60} gamma radiation ranging from 100 to 400 r indicate that the effects on sperm count could generally be correlated with the dose. The larger the dose, the greater the damage to the sperm, resulting in a decrease in sperm count, decrease in live sperm, and a decrease in the motility of the sperm. These changes reached the maximum during the 9th to 16th week following exposure. By the end of the 24th week all abnormal changes had returned to near normal conditions.

Hereford cows exposed to single doses of gamma radiation ranging from 100 to 400 r showed no observable effects on fertility up to 2 years following exposure. Doses in the lethal range are necessary to produce sterility. Lower exposures at the proper time in gestation may cause fetal aberrations. Genetic changes can be assessed only when there is a well known background mutation rate in animals.

Epilation has occurred in cattle and sheep following exposure to gamma radiation. This loss of hair is not to be confused with the beta burn.

Certain radionuclides in sufficient quantity within the body produce a total body irradiation syndrome. The phenomenon has been observed in sheep and dogs after injected doses. Concentrations of strontium and iodine have produced neoplasms in domestic animals. The thyroids of cattle contain much higher concentrations of radioiodine from nuclear detonation and reactors than do the thyroids of man due to grazing or feeding practices.

Many suggested maximum permissible levels of body burdens for radionuclides in animals have been proposed. For the most part they are not based on the effect on the animal but as a limitation to the concentrations passed on to man through animal products such as milk. Where maximum permissible levels for animals have been suggested, the concentrations suggested seem to occur under conditions which at the same time would have produced hazardous total body irradiation.

Particulate matter in fallout has lodged sufficient radioactive material in the coats of grazing animals close to nuclear detonations to produce beta burns in the hides. These lesions are characterized by epidermal atrophy, keratosis, and necrosis

depending upon the severity. They may heal completely, leave a smooth weakened skin with discolored hair, or form permanent scar tissue. Experimentally, it takes thousands of rads of beta radiation to cause a beta burn. None of the animals accidentally exposed and observed had other physical signs of exposure.

From data contained in reports to the Subcommittee on Radiation of the Joint Committee on Atomic Energy and reports of the New York Operations Office of the Atomic Energy Commission, we have noted that animals in relatively heavy concentrations of radiocontamination, such as the Nevada Test Site or Rongelap, did not assimilate proportionally higher concentrations of Sr^{90} over a period of 2 years. Factors other than absolute concentration seem to have been operating.

Limited experimental evidence and field testing indicate that animals in the path of a fallout which fail to develop beta burns will ordinarily escape serious external radiation injury and the radionuclides from that cloud will be practically innocuous to the grazing animal.

It is theoretically possible to produce an area of high radio-contamination by overlapping non-simultaneously arriving fallout. In such a case there might be no beta burns on the skin of animals but radiation injury would be due to total body irradiation from ground concentrations or the ingested mass.

Animals that sustain exposure intense enough to produce beta burns but live longer than 3 weeks or a month fall into the same category as those without burns.

Other grazing animals will have received a fatal total body exposure dose and both external beta irradiation and irradiation from ingested sources are of no consequence.

It is suggested that the limiting factor for survival following a nuclear attack will be man and not the animal. The use of animals and animal byproducts may reduce the hazard of radio-contamination following nuclear warfare below that which must be tolerated if food is obtained directly from plants. Although total body irradiation and intestinal doses from absorbed isotopes will be much higher for animals, their relative faster maturity and reproductive cycle will compensate for some of the changes produced by the increased radiation. Losses due to increased incidence of disease from a disorganized society are apt to be a much greater immediate hazard to survival than the latent effects of irradiation.

Total Body Irradiation

In 1912, Regaud et al., wrote about the effect of ionizing radiation on the intestinal mucosa of the dog. Since that time many domestic animals have served the investigator in his quest for knowledge concerning the biologic effects of radiation. It is enigmatic that massive doses of radiation are required to produce observable chemical changes and yet relatively small amounts of radiation kill. If the total exposure is accomplished in less than 24 hours, between 300 to 600 r usually destroys about 50 percent of mammals. The midlethal dose for common species of livestock

at 30 days ($LD_{50/30}$) may be found in Table 2. Some species seem to be more radiosensitive than others. However, considerable variations in lethal response are found in families or even among individuals of the same species. Vegetative forms such as bacteria are more radioresistant than mammalian forms. Physical as well as biologic variations make comparisons of results from different laboratories difficult.

TABLE 2.—MIDLETHAL DOSES OF IONIZING RADIATION

Species	$LD_{50/30}$(r) 1/	Radiation 2/
Cattle	550	Co^{60}, 60 r/hr
Burro	784 651 585	Co^{60}, 50 r/hr Ta^{182}, 18-23 r/hr $Zr\text{-}Nb^{95}$, 20 r/hr
Sheep	525	$Zr\text{-}Nb^{95}$
Swine	618	Co^{60}, 50 r/hr
Poultry	900	Co^{60}, 60 r/hr
Dog	228-252 265-312 335-530 335	X-ray midline dose X-ray air dose X-ray, 21-500 r/hr Co^{60} midline dose
Rabbit	767 1,633 1,094	250 kvp 80 kvp Co^{60}
Parasites	25,000	X- or gamma
Bacteria	50,000 500,000	X- or gamma

1/ $LD_{50/30}$ = The quantity of radiation in roentgens (r) that killed 50 percent of the test animals within 30 days after exposure.

$LD_{50/30}$ has not been determined for bacteria or parasites and the near sterilization doses quoted for them above are given only to show the relative radioresistance of these forms.

2/ Mev = Million electron volts; kvp = kilovolt potential; r/m = roentgens per minute, a dose rate. Midline dose = dose measured at the approximate physical midcenter of an animal torso. Air dose = dose measured in air at point where the approximate physical midcenter of animal would have been during irradiation.

Dose

The expression of dose as used is itself variable since the roentgen, by definition, is an expression of quantity of energy absorbed by air. It is used to designate "free

in air dose," "midline dose," and "absorbed tissue dose" as in Table 2. Regardless of these variations, the biologic effects are in relation to the expressed dose. The dose is additive with various radiations and cumulative in a certain sense insofar as effects of previously received irradiations have a demonstrable effect upon the response to subsequent irradiations. The $LD_{50/30}$ for rats was reduced by 60 percent when re-exposures were made at 60 days.

Intensity

In man, it has been found that radiation of low intensity has little recognizable effect on the skin which has been explained as meaning that the lesions are being repaired as fast as they are produced. However, with radiation of moderate intensity at least, the effect is proportional to the dose.

Dose Rate

Experiments have shown a reduction of lethality by 70 percent of a given dose when the exposure time (dose rate) was increased tenfold. The amount of radiation to elicit a cutaneous reaction in man was doubled when doses were lengthened 30 times. The $LD_{50/30}$ for dogs at various roentgens per hour varies considerably (Table 3). Mice exposed to similar doses in 90 minutes and in 24 hours from Co^{60} had an $LD_{50/30}$ of 930 r in one case and 1,325 r in the latter.

TABLE 3.—LETHAL EFFECTS OF WHOLE BODY RADIATION OF DOGS

Rate (r/hr.)	$LD_{50/30}$(r)
456.6	335
160.0	430
21 to 25	530

Fractionation of Dose

Fractionated doses and the continuous administration of radiation may differ in their effectiveness. However, if the fractionation is not great the difference may be insignificant. It may be possible to measure these differences but it is difficult to explain them.

Rats have been exposed to acute and fractionated exposures and it was found that a 600 r acute dose reduced the life span by 19 percent. When the dose was given in 10 daily doses of 60 r each, the life span was reduced 5.8 percent whereas there was no significant reduction in the life span of rats given 600 r in increments of 20 r a day.

Swine have been given fractionated doses of 50 r/day until death and accumulated a mean lethal dose several times greater than the burro. The burro proves to be more radiosensitive when exposed to fractionated doses of 100 r/day. It is also of

interest that the guinea pig ($LD_{50/30}$, 200-400 r) and the burro, although quite different in their response to acute whole body irradiation, have a similar response to the fractionated doses (Table 4) while the rat is quite different.

TABLE 4.—MEAN SURVIVAL TIME FOR ANIMALS EXPOSED TO DAILY DOSES OF IONIZING RADIATIONS

Daily dose	Mean survival (days)		
	Burro	Rat	Guinea Pig
90-100 r	23.3	48.4	20.2
20-30 r	63.0	332.6	68.8

Quality of Radiation

The quality of the radiation is a factor in biologic effects. By quality, we mean the type and energy of radiation or, in the case of X-rays, the characteristic spectral energy distribution. Arbitrarily, we will speak of low-energy X-rays as those under 140 kev, relatively high-energy X-rays as those between 140-250 kev, and high energy X-rays as those between 250 and 3,000 kev. All gamma energies of nuclides used in whole body radiation studies have been in the high-energy range.

Generally, the term quality refers to the penetrating power of the radiation which is directly related to energy. However, biologic effects are caused, as mentioned previously, by energy transfer or total absorbed dose. This depends not only on the quality of radiation as the initial energy of photon, but also the degradation of photons, geometry, and the tissue characteristics of the animal target.

Relative Biological Effectiveness

The inverse ratio of the doses required of different radiations to produce a standard amount of given biologic effect is the relative biological effectiveness (RBE) of the radiations. The difference in properties of radiation can be determined properly only when the physical measurements throughout the target are accurately known—a most difficult task. To express differences measured by "biological dosimeters" and "air dose" comparisons, RBE is often used. It will be recognized at once that the RBE for various radiations will be greatly influenced by the "end point" observed. The lethality of a radiation is perhaps the most common reference, however, carcinogenesis, cataract formation, and erythema are other biologic phenomena which have been used as "end points".

Burros were exposed to gamma radiation from 3 radionuclides, each with a different mean energy. The results, given in Table 5, show a variation in $LD_{50/30}$. Since the slower dose rate or the lesser depth dose of diminishing energies should have reversed the results, we may assume that a more important factor was involved. If it were a physical factor, then we may assume it to be a function of linear energy transfer (LET).

TABLE 5.—LETHAL RESPONSE OF BURROS TO NUCLEAR RADIATIONS

Source	Mean energy	Lethal dose (95 percent confidence)	Rate (r/hr)
Co^{60}	1.25	784(753-847)	50
Ta^{182}	1.20-0.18	651(621-683)	18-23
Zr^{95}-Nb^{95}	0.74	585(530-627)	19-20

To recapitulate, the physical factors of type and quality of radiations, dose, dose rate, dose fractionation, and relative biological effectiveness determine the response of the mammal to radiation. In addition to these factors, there are physiologic factors that must be taken into consideration.

Physiologic Factors

The body size of the animal seems to have very little to do with the response to ionizing radiation, as a perusal of the $LD_{50/30}$ (Table 2) will indicate. The metabolic rate of the species also has little to do with radioresistance, although both of these factors may have a slight bearing on survival of individuals. Sex differences in radiosensitivity have not been consistently demonstrated in the larger domestic animals. Mice under 15 days old survive longer than 30-day-old mice when irradiated, but animals over 30 days old become increasingly more radioresistant. Mice from 45 days to a year old show little difference in response to radiation.

When it was found that swine may survive several times as long as burros while receiving the identical daily dose of gamma radiation, it was assumed by some that the fat of the swine protected in some manner. There have been reports that because of the low effective atomic number of fat, it can account for a small difference in sensitivity. In the case of the swine, however, the acute radiation studies indicated they were more radiosensitive than the burro, thus the fat was not a factor involved.

Biochemical Changes

Only a few of the biochemical changes will be mentioned to show the possible ramifications. The effects on pure or simplified systems, for example, are not to be discussed. An understanding of the biochemistry, of the irradiation injury is the best hope for a rational and effective approach for the alleviation of the radiation injuries. So far, with some few exceptions, these hopes have not been realized. The studies made with the changes in enzymes and enzyme systems should hold considerable promise but to date little has been accomplished. The opinion has been expressed that, with rare exceptions, increases and decreases in enzyme activity in irradiated animals are artifacts. It must be emphasized, however, that any biochemical alteration must, in the final analysis, be associated with changes in enzymes, coenzymes, substrate, or habitat. Therefore, the efforts in this field must continue in spite of the present lack of success.

Radiation Syndrome*

The syndrome of radiation sickness in large animals has been reviewed. Studies have pointed out that there is no single clinical reaction specific for irradiation damage. Many of the effects can be duplicated by other toxic agents. However, the clinical response to single or daily doses of external irradiation or acute internal whole body irradiation forms patterns of a similar course of observable signs. In general, these are: anorexia, cachexia, electrolytic imbalance, capillary fragility, and subsequent effects such as increased loss of injected chemicals or dyes and characteristc hematologic changes, which are to be described separately. Other changes are dehydration or fluid imbalance within tissue spaces, fall in blood pressure, increased catabolism, and such changes indicative of tissue breakdown as may be further reflected in weight loss and death or eventual reparation and recovery. Finally, a complex of chronic irradiation effects occurs, which is commonly referred to as "premature aging."

For the first few post-irradiation days, the burros appeared to be in good health. Then followed a 4 or 5-day period of apathy. Increased irritability and hyperesthesia, decreased food and water consumption, and a few deaths occurred. For the next week or so, there appeared to be recovery, some animals appearing euphoric but ultimately there occurred a period of apathy and inappetence accompanied by severe weight loss.

Animals surviving near lethal doses bled from small wounds or venipunctures or oozed bloody serum from mucous surfaces after the second week. Edema of head and throat was observed and shortly thereafter a second wave of deaths occurred.

Vomiting, not a physiologic function of the burro, occurs post-irradiation in swine and dogs.

Rhinitis and bloody diarrhea, although seen in small laboratory animals and dogs, goats, and swine, were not seen in burros after irradiation.

Gross gingival ulcers in burros and dogs make an offensive malodorous mouth in the radiation sick of these species. No coat loss was seen due to experimental gamma irradiation. Goats, however, had loss of hair when exposed to radiations at the Bikini detonation in 1946.

Special areas of the burro's hide, a small differentiated patch of skin above the external tarsus and the skin of the forearm, seemed to itch after irradiation. A few burros had licked or scratched these spots until large sores were created.

Early eye lesions consisted of conjunctivitis, keratitis, corneal ulcers, nebula, leukoma, and corneal vascularization. This complex should not be confused with delayed lenticular opacities following X- or gamma radiation. The eyes of animals with conjunctivitis wept copiously and the conjunctiva became edematous, particularly in swine, and ectropion occurred. These lesions of the eye are caused by ionizing radiations.

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* For additional information on man see section "Results of Exposure," page 124.

Burros and swine have had neuromuscular spasms following irradiation even in median lethal ranges. Twitching of facial muscles and spasmodic retraction of the lips were occasionally seen within 48 hours after exposure. The condition known as "stringhalt" in which the hocks act in an exaggerated jerky movement is often seen. Knuckling over of the fetlock joints has been reported in irradiated sheep and burros and is frequently present in exposed cattle. Hopelessly sick burros pop joints and quiver muscles while standing and bob their heads up and down in jerky motions. These observations are not commonly reported as happening in other experimentally irradiated animals, however.

Although this sign was not reported in other irradiated mammals, the burro may react to whole body radiation exposures in the range 500 to 1,000 r similarly to the horse with encephalitis. Incoordinate waling, circling, and pressing against walls with the head are some of these signs. The sign does not indicate ensuing death, since some affected animals have recovered. The micropathologic changes of the brains of fatal cases did not suggest that an infective agent was involved.

Lameness, seen to some degree in all species of animals irradiated on the University of Tennessee-Atomic Energy Commission exposure field at Oak Ridge, Tennessee, is not well understood. It appears early in the irradiation syndrome, is a function of weight support and not a performance type, a sort of leg weariness which is transient.

Another clinical observation of interest was the observance of an irradiated hog after a large (10 $cm.^2$) area of skin and flesh had sloughed from its hock. Although the surrounding tissue was necrotic, the ligaments eroded and the bones became clearly visible; there was no redness, swelling, pus, or pain. The animal walked with very little dysfunction of the open joint. We have been told that dogs, whose bones have fractured due to irradiation from internal radiation, have been observed to show no pain and may try to walk on the fracture if not restrained.

The signs of whole body radiation sickness observed in an animal depend on the radiation dose, rate of administration, and survival time. All or none of the signs enumerated may occur in any one case. Similarly, the mode of death is variable. In all groups of experimental animals, there have been waves of mortality. Certain significance has been attached to these waves.

Between the most massive of radiation exposures and death, there is a latent period. It may be a matter of minutes after kiloroentgen exposures or a matter of years.

A shocklike reaction and death follow supralethal doses of radiation within a few days. When deaths occur after the third day they are usually attributed to severe intestinal damage. After the peracute deaths, there was a period during which animals appeared nearly normal, which was followed by a wave of deaths generally considered to be caused by septicemia or hemorrhage. All animals destined to die of the acute radiation syndrome died within 30 days with few exceptions. Low lethal doses or extended irradiation time may stretch out this mode of death for several weeks.

Other animal survivors of doses as low as 25 r/week for 14 weeks, died after 3 to 5 years with a record of progressive leukopenia and thrombocytopenia. Clinically, they were normal appearing animals until the time of their deaths.

It had been recognized for years that the blood-forming tissues are among the most radiosensitive. The effects may be summarized as a dose-dependent reduction in lymphocytes, thrombocytes, polymorphonuclear leukocytes, and erythrocytes, as well as a clotting defect resulting in petechiosis or hemorrhage.

The hemorrhagic syndrome of goats and swine after atomic bomb exposure was considered to be predominantly a result of a combination of increased vascular fragility and thrombocytopenia. The clotting defects were infrequent and the causes inadequately explained. Subsequent experimentation indicated that the loss of thrombocytes resulted in the clotting defect. Concurrent with a reduction in platelets and typical pancytopenia in post-irradiated dogs was a loss of prothrombin utilization.

The cytologic changes in the blood of irradiated burros have been summarized as follows: Erythrocytes were reduced in burros following total body exposure to gamma radiation. Hematocrit and hemoglobin values followed the same pattern of response as the red blood cells. An increased erythropoiesis, demonstrated in bone marrow from the 10th to 20th post-irradiation days, was soon reflected by an increase in the peripheral blood of burros, significantly increased in the marrow from the 5th to 10th week.

Changes in the white blood cells were principally a reduction in lymphocytes during the first two weeks. The minor reduction in neutrophiles was greatest about three weeks after exposure to the radiation. It was observed that animals failing to check a fall in neutrophiles at this time died whereas others made gradual recovery. Monocytes were reduced. There was an absolute eosinopenia but a relative eosinophilia. Sedimentation rate increased linearly with decrease of red blood cells, suggesting little change in the plasma proteins in the irradiated burro.

There was a retardation of whole blood clotting time, a clotting defect in recalcified oxalated plasmas, a lessening of clot retraction, and pronounced diminution of prothrombin utilization rate.

The clotting defect in burros was expressed in nearly direct relation to decrease in circulating thrombocytes. However, the defect was apparent with less than 20 percent reduction in platelets. Recovery occurred while platelets were less than 50 percent normal.

The effects of whole body irradiation have been observed upon the blood cells of rabbits within 15 minutes. The effect, a reduction in lymphocytes, was not great below doses of 25 r and there was a return to normal within 24 to 48 hours. However, in the LD_{50} range, the recovery of lymphocytes is the last to be noted in the hematopoietic system along with the platelets. In fact, burros having received doses from 350 to 530 r (air doses which were not acutely lethal) had not fully recovered normal blood counts 2 years after irradiation.

Although capillary fragility was detected in all irradiated animals, the flooding of lymphatics with red blood cells was never so extensive in the burro as in the hog or other animals. The simultaneous loss of fluids as well as red blood cells has resulted in a masking of individual hematopoietic effects.

Death attributable to frank hemorrhage in large animals was rare and usually attributed to a traumatic injury or organ capsule rupture. Clotting, although delayed, is not otherwise affected within the tissue of intact animals as in the test tube due to adjacent tissue factors. However, clot retraction is improved little, if any, by these tissue factors.

In summary, the characteristic blood picture of the irradiation syndrome in large animals may be:

(a) An immediate decrease in numbers of circulating lymphocytes with a slow recovery rate, if doses are near lethal range.

(b) A lesser and slower reduction and faster recovery of polymorphonuclear leukocytes and erythrocytes.

(c) A clotting defect related to a thrombocytopenia and characterized by a slower clotting time and impaired clot retraction which appears about 2 weeks after exposure and usually repairs quickly; however, relapses have been encountered.

(d) The peripheral blood changes reflect changes more quickly than the lymphopoietic system whereas morpholigically the erythropoietic system reflects a radiosensitivity and prompt recovery.

(e) The evidence for the existence of radiation ''stimulation'' of hematopoiesis is weak.

Pathology of Radiation

Gross autopsy observations in animals exposed at Bikini have been described: Gross hemorrhage with blood clots in pelvis of the kidney in goats and pigs; lymph glands enlarged and hemorrhagic; brain and meninges retentive; purpura of skin sometimes seen; the lungs dripped a blood-stained fluid and had dark patches resembling hemorrhage in lobar pneumonia; consolidation was seldom seen; the gastrointestinal tract had acute ulcerations, never deeper than the submucosa, if death occurred in 3 or 4 days. Liver, spleen, and adrenals were normal.

The conditions affecting survival and the clinical syndrome also affect the pathologic picture. For instance, an animal must live sufficiently long for blood dyscrasias to appear. Species like the burro do not pour young erythrocytic cells into the circulation as other species might. Their lymph and spinal fluid are relatively clear at stages of the irradiation syndrome when that of swine is apt to be well mixed with blood. Animals that die rapidly following irradiation show either none or very few gross pathologic changes.

Frank hemorrhages occurred when organ capsules were ruptured by trauma of handling, migration of internal parasites, fighting, or normal physiologic functions like ovulation. Large perivalvular ecchymoses of the heart and hemorrhages about the Purkinje fibers were observed.

The stomach of animals dying of radiation sickness is usually filled either with ingestia or fluid. The pyloric sphincter is abnormally tight and will not permit emptying without considerable pressure.

Under certain conditions, epiphysial breaks are caused by manipulations that would not induce fractures under normal circumstances. Arthritis, although commonly seen in swine following irradiation, is seldom seen in sheep or burros.

Spontaneous ulcers of skin occurred in some swine that were irradiated repeatedly. Only after a traumatic wound, sometimes self-inflicted by biting or licking, were ulcers of the skin in burros observed with the exception of those found commonly on the face, muzzle, or forehead.

Wounds, contrary to expectation, never appeared serious per se, although the healing process in radiated animals is not well understood. No pus was observed to accumulate in wounds that would ordinarily become suppurative under the conditions in which the animals live. The wounds on survivors heal slowly but without other complications.

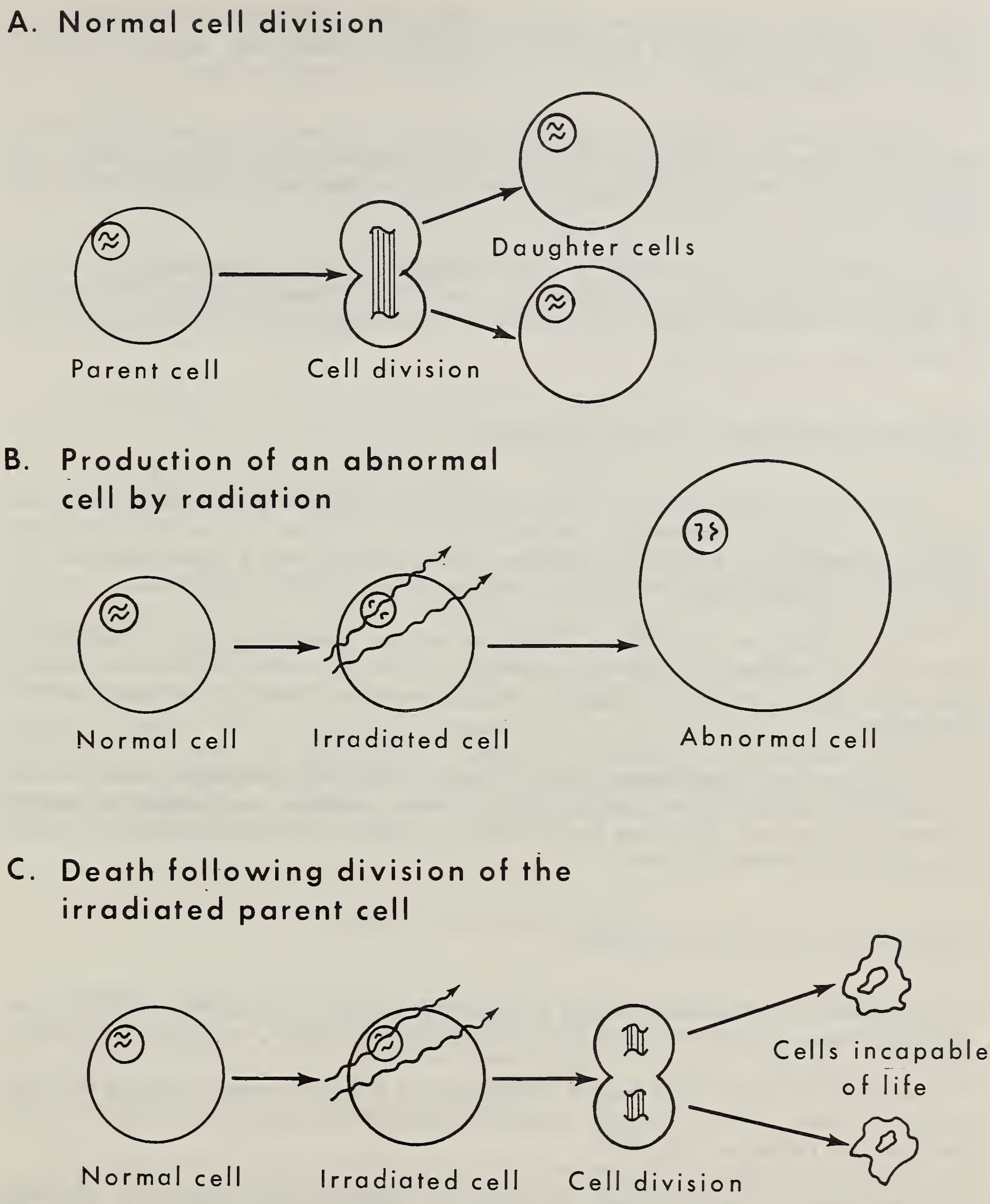
No epilation was observed in the experimental irradiation syndrome but occasionally the hair would strip very easily from hogs that died of irradiation sickness. Twenty or more hogs receiving a minimum of 500 r were slaughtered the following day with controls. The hair on the irradiated hogs did not have to be scraped off after scalding as on the non-irradiated but could be removed by hand wiping. No investigation or explanation of this phenomena was attempted.

In some animals, total body irradiation with 400 to 500 r of X-radiations may cause damage to hair follicles with epilation possible in about 3 weeks. This effect may be permanent or temporary. The glands of the skin have a specific sensitivity to ionizing radiation with hair follicles, sebaceous glands, and sweat glands being affected in that order.

The histopathologic changes leading to these effects are briefly: Degenerative changes of reversible or irreversible nature; inhibition of mitosis or abnormal mitotic figures. It is perhaps impossible to use the observed death of the cell as a criterion of damage. Occasionally, mitosis ceased within one-half hour after total body irradiation and recovered within 12 hours. Even then, not all cells of all tissues respond alike. Doses that affect epithelial and connective tissues may have little effect on nerve and muscle. Lymph nodes are extremly sensitive to total body irradiation and respond with the death of lymphocytes and reduction in size of organ. (See Fig. 21 - Effects of Radiation on Cells.)

Bone, histologically a connective tissue, responds by showing hypertrophy of cartilaginous cells, loss of normal interdigitation of cartilage in spongy bone, and arrest of growth. The latter effect may be of serous consequences in radiation therapy of growing bones.

Irradiation of the ovary leads to atrophy and sterility. Formed corpora lutea are not affected by doses damaging to the ovary. The presence of the hemorrhagic



BN-13625

Figure 21.—Effects of radiation on cells.

phase at time of ovulation may interfere indirectly with the function of the corpus luteum. Supralethal doses of whole body irradiation are necessary to affect the ovary grossly and permanently.

Histopathologic changes in the thyroid gland have not been observed following total body irradiation but the destruction of the gland may be brought about by large local doses. However, physiologic changes due to total body irradiation have been seen.

In summary, it seems that there is no specific gross or histopathologic picture of radiation death. Within certain dose limitations, however, it is often possible to diagnose radiation injury by a summation of changes and a consideration of the relative tissue sensitivities.

Infection and Immunity Effected by Radiation

Studies have indicated that irradiation of the body of mice would reduce their ability to produce antibodies. Ionizing radiation reduced or abolished active or passive immunity to bacterial infections. The response was a function of dose with significant changes occurring when the exposure was greater than 200 r.

The irradiation of rabbits, 2 days to several weeks previous to the administration of an antigen, completely inhibited antibody formation. It has been reported that total body irradiation after the antigen injection would not suppress antibody formation.

The transient morphologic changes due to total body irradiation, such as occur in lymphoid tissue, bone marrow, and gonads, recover long before the immune system is repaired. This has been taken to indicate the disassociation of antibody formation and lymphoid tissue.

Reproduction and Radiation Effects

In general, irradiation effects in reproduction are: Reduction in fertility, embryologic aberrations, retarded fetal or infant development, and genetic mutations.

A group of 60 female burros, survivors of lethal dose experiments, were observed to have normal estrous cycles 4 years after exposure (300-530 r) of total body gamma radiation with Co^{60}.

Complete, permanent male sterilization apparently does not occur following sublethal doses of total body irradiation, although relatively small doses (50 r) may produce histologically recognizable changes in the germinal epithelium. Male survivors of exposures in the lethal dose range remain fertile for a few weeks, gradually become temporarily sterile and recover concurrently with an adequate repopulation of spermatogonia. The response indicates a relative sensitivity of spermatogonia and resistance for sperm, spermatids, and Sertoli cells.

Three days after exposure to 750 r of gamma radiation, a reduction in spermatogenesis was histologically apparent in burro testes. Survivors have a complete cessation of spermatogenesis at 30 days and histologic signs of recovery 65 days after exposure.

However, even in human populations with reasonably good vital statistics there is a great latitude in estimates of the average spontaneous mutation rate. Spontaneous mutation rates for aberrations in a domestic animal are too unreliable to make an index. It would be impossible to detect radiation-induced mutations in offspring or even later generations unless vast numbers of clear-cut abnormalities could be distinguished circumstantially from increases caused by other changes in mode of living such as the introduction of mutagenic antibiotics, pharmaceuticals, industrial pollution. or foods.

Zootechnically, a selective multiplication of advantageous mutants is ordinarily practiced by animal husbandrymen. A rationally directed selection of breeding stock can eliminate individuals having an excess of undesirable mutant genes. Therefore, there is little concern for a potential increase in mutation rates of domestic animals due to ionizing radiations.

In recapitulation, it may be stated that the problem of reduction of fertility in domestic animals by exposure to ionizing radiations is not serious. Acute doses, large enough to cause permanent fertility impairment, will seriously affect all animal life to a far greater extent.

Mutations due to radiation cannot be distinguished from other naturally occurring genetic changes. Vast numbers of animals would have to be observed for many generations to detect an increase in frequency of phenotypic expressions of mutations. As a matter of fact, due to the practice of selective breeding the opportunity for stock improvement should equal or exceed deleterious effects.

External Beta Radiation Effects

The beta particle, because of its lack of penetration or, said in another way, because its energy is totally absorbed by small thicknesses of skin, cannot cause total body irradiation death. Massive doses applied to great surfaces of the skin may cause death. The radiologic action is, like that of all ionizing radiations, subject to energy (quality of radiation) and dose.

The first observed casualties of nuclear weapons were cattle exposed to beta radiation of fallout at Alamogordo. Except for the superficial skin lesions, these cattle lived a normal productive lifetime. Horses too, have been recipients of "beta burns" caused by fallout on the gunnery range at the Nevada Test Site.

Particulate matter of fallout, containing radioactive elements, when lodged on the hide or in the coats of animals may be close enough to deliver large doses of beta radiation to the skin.

The external or contact effect due to fission product decay during or following nuclear detonations is principally the result of beta radiation. Particulate matter lodging on the coat or skin of the animal brings the radioactive elements into position sufficiently long enough to produce what has been called "beta burns." One marked difference between thermal burns and beta burns is the immediate response to the former and the latent response to the latter. Several days or weeks may pass before physical sings of the beta burns are apparent. The lesions may be classified as:

(a) Epidermal atrophy which follows a low dose of radiation. Although a slight depigmentation of the coat may be seen a few weeks after exposure, the skin is usually intact and atrophy recognized only microscopically.

(b) Exfoliative keratosis which follows a more intensive exposure, in which the skin becomes flaky and exfoliated. A chronic radiation dermatitis usually follows this type of burn. A typical cell forms are characteristically found in the epidermis, hair follicles are usually destroyed, and the surrounding tissues produce a depigmented coat color.

(c) Transepidermal necrosis, the severest type of beta burn which except for the latent development mentioned above, resembles a thermal burn with edema, bullous desquamation, and loss of hair. An atrophic epiderm may eventually cover the lesion but the coat will not regrow. Around the edges of such a wound may be found the lesions characteristic of the two lesser types of beta burns.

Having clipped the wool from one side of yearling lambs, both sides were exposed to doses of gradients from 1,000 to 30,000 roentgens equivalent physical (rep). On the clipped side, doses above 3,000 rep produced visible lesions; others did not. Although observed for 100 days, no lesions were seen on the side exposed while the wool was on, lesions were noted on the 25th post-irradiation day in some of the shorn sheep. No lesions were produced when exposure was made through wool at the 5,000 rep level and only pink discoloration of skin and loss of some wool resulted at the 20,000 and 30,000 rep level.

Experiments indicate that sheep are naturally well protected from beta radiation damage from fallout by the thickness of their wool.

Questions

1. Impaired fertility due to total body irradiation is of slight significance because:

   a. the sterility is transitory,

   b. a supralethal dose is required to impair fertility,

   c. a sublethal dose produces sterility, or

   d. radiation induced sterility is a factor in old age only.

2. Animals exposed to fallout but that fail to develop beta burns:

   a. still may die from gamma exposure,

   b. often will develop severe radiation sickness,

   c. will be limited to a moderate sickness from gamma exposure, or

   d. as a rule will show no harmful effects from gamma radiation.

3. A simple laboratory test to be used as an aid in diagnosis of radiation sickness would be:

   a. a blood count,

   b. bone analysis,

   c. thyroid section and analysis, or

   d. laboratory examination of the cornea.

4. The most frequent carcinogenic effect of total body irradiation is:

   a. carcinoma of the thyroid,

   b. leukemia,

   c. sarcoma of bone, or

   d. carcinoma of the skin.

PART II

MEASURING RADIOACTIVITY[1/]

Nuclear radiation is not detected by any of the five human senses, but instruments have been developed that detect and accurately measure it. Field instruments, which measure the beta and gamma radiation associated with fallout, are required. Neutrons will be present in the initial radiation and alpha particles will be present in fallout. Their importance relative to that of beta and gamma rays is such that field measurements of alpha and neutron radiation are not required.

There is no equivalent of combat experience upon which to base the requirements of radiological instruments. Test bombs of various yields have been detonated under various conditions. Many variables influence the concentration of residual radiation that might be encountered—bomb size, place and height of detonation, type of bomb assembly, and meteorological conditions. This being so, it is not possible to predict accurately the radiation levels that could result from fallout. Moreover, the effects of radiation upon people must be the major consideration. Hence, for practical consideration of effects of radiation on personnel, the gamma instrument must respond accurately to dose rates as high as 500 r/hr. Intense beta radiation fields would probably exist, so detection of beta radiation is required.

Choosing the maximum sensitivity is much simpler. Rather small increments above background will need to be detected in checking contamination of food and personnel, and other circumstances where the early detection of above normal concentration of activity is important.

Instruments used in the measurement of radiation dose rate are required to have a direct reading scale. Blinking lights, audible warnings, or "go-no-go" indications are not satisfactory. The radiation dose rate should not be the criterion. Rather, dose rate times time, or dose rate times length of exposure, is the critical factor. Therefore, if a particular dose rate is chosen as the "go-no-go" value, the expected duration of the exposure is also fixed. Exposure time, as well as allowable dose, will depend on the urgency of the situation and cannot be determined beforehand. Radiation dose rate meters are basically reconnaissance instruments. They provide the information required to make maps of contaminated areas which show rough contour lines of dose rates and indicate local hot spots. They provide the information required by civil defense officials in directing civil defense operations.

Estimates of exposure can be made on the basis of dose rate measurements, decay rates, and probable exposure time; but these estimates should be used for planning purposes only—the actual determination of exposures must be made by measurements. The dose measuring devices (dosimeters) must be self-indicating,

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1/ Prepared by Samuel E. Grove, Meat Inspection Division, Agricultural Research Service, U. S. Department of Agriculture.

that is direct reading, if they are to be used by the wearer to check his accumulated exposure. OCDM recommends the use of two operational dosimeters, 0 to 20 r and 0 to 100 r, for use by the organized civil defense services. Where expected exposures are small, or where small repeated doses may be received, the lower range dosimeter is used. Dosimeters covering higher ranges are also recommended for these workers to measure exposures received at time of bomb burst or accidental or necessary over-exposure during post-explosion activities. Without such information workers might be asked to undertake duties involving additional exposures which would be very hazardous if added to previous over-exposure.

Instruments for Measuring Radiation Rate

Instruments that measure the rate at which radiation is received may be divided into two types — one in which gas ionization tubes are used, the other in which phosphors or scintillation media are used. Both types may be calibrated in roentgens or milliroentgens per hour or in curie units reflecting the disintegration rate of the substance being measured. The latter determinations generally are made only in the laboratory. There is no one simple, yet sufficiently accurate, instrument to measure all ranges of dose rate. The extremes of sensitivity are not required in any one single operation; therefore, the OCDM has recommended the use of three different survey meters. They are: (a) Geiger-Mueller meter, (b) medium range gamma survey meter, and (c) high range beta-gamma survey meter.

Geiger-Mueller Meters

This type survey instrument derives its name from the Geiger-Mueller (G-M) tube that it uses as its detecting element. The principal elements of the portable Geiger counter are: (1) The G-M tube with its housing; (2) the electronic circuit; and (3) the meter or indicating mechanism.

1. A geiger tube is a two-element electronic tube that gives a large, uniform-size current pulse when an ionizing event occurs within its sensitive volume. In essence, it is an electronic amplifier tube that produces the same size pulse regardless of the initial ionizing event. The output pulse from the geiger tube is fed into an amplifier which in turn activates a speaker or earphones and a metering circuit. Each pulse produces one click in the earphones and represents one ionizing event in the geiger tube. The meter reading is proportional to the number of ionizing pulses occurring per unit time and, therefore, proportional to radiation intensity. Geiger tubes are often sensitive to ultraviolet light and, therefore, are usually painted black to keep light from entering. Scratches in this paint covering can allow a response to intense light sources. The voltage must be well up on the Geiger-Mueller region if the instrument is to operate properly. Operating voltages are generally in the vicinity of 1,000 volts. The filling gas is usually argon which, when irradiated, yields ion pairs. These ions are accelerated by the electric potential and produce hundreds of millions of secondary ion pairs. Generally, the tube wall is the cathode and the wire traversing the axis of the tube is the anode.

2. The electronic circuit is necessary to deliver the desired voltage to the G-M tube. This is usually supplied by batteries. The circuit also receives pulses from the tube and amplifies them so that each can be heard as a click through an earphone or speaker, or so they may be measured as a current by the meter of the instrument.

3. The indicating mechanism may be either earphones or a meter. Most Geiger-Mueller survey instruments are equipped with both. The pointer or needle will waiver slightly in operation and an average reading should be used. This instrument has a switch for selecting different ranges of sensitivity. The operator must be careful in selecting and reading the proper scale.

The Geiger counter is a beta-gamma discriminating counter for high sensitivity requirements, for long range follow-up, and for training purposes. This instrument is also suitable for food, water, and personnel monitoring. The ranges are 0-0.5, 0-5, and 0-50 mr/hr, calibrated against gamma rays from cobalt-60 or radium. This instrument, like any other instrument designed for sensitive measurements, would have limited utility in an area of significant contamination since a relatively low background would drive it off scale. In such an event, the instrument would have to be used in an area well shielded from the fallout radiation where food, water, and personnel could be brought for the contamination checks.

Ionization Chamber Instruments

Ionization chamber instruments are insensitive to low levels of radiation but are quite reliable in indicating high-level intensities. Ionization chambers are usually about 12 to 50 cubic inches in volume and filled with air at atmospheric pressure. The design of the chamber and the type of material used in its construction determine the type of radiation to which it is sensitive. The larger the chamber, the more sensitive the instrument, but also the greater the voltage required for operation. Operating voltage of 90-200 volts is supplied by batteries. The current which flows is equal to the primary ionization and is directly related to the quantity of radiation in the chamber. With chambers equipped with special shields it is possible to distinguish between the different types of radiation. Many types of ion-chamber survey meters are designed to measure high intensities of gamma radiation only. Most survey meters incorporate a circuit for changing the amplification by factors of 10. This enables the operator to vary the instrument's range and sensitivity. Some meters have only one scale and the operator must multiply or divide the reading by the appropriate multiple of 10, if he uses a range other than that which gives direct readings. Other instruments have several scales printed on the meter, and the operator must then determine by the range setting which scale to use. To insure accuracy, each instrument must be individually calibrated against radiation of the same type as that to be measured.

CIVIL DEFENSE SURVEY METERS

CD V-700 Geiger Survey meter, beta-gamma discriminatory (0-50 mr/hr)

CD V-710 Ion Chamber, gamma only (0-50 r/hr)

CD V-720 Ion Chamber, beta-gamma discriminatory (0-50 r/hr)

Instruments for Measuring Radiation Dose

Instruments for this purpose are used for personnel or area monitoring to determine the total dose of radiation received during the period of exposure. The types in general use at the present time are:

1. Electroscopes
2. Photographic emulsions
3. Chemical indicator solutions
4. Glass dosimeters
5. Neutron detectors

Electroscopes

The electroscope or electrometer is an instrument for detecting or measuring an electrical charge. If a charge is placed upon an insulated electrode, it will remain constant unless neutrailized or allowed to leak away. Ions formed in a gas by radiation cause the gas to become conducting. If the ionized gas surrounds the charged electrode, the charge leaks off at a rate proportional to the degree of ionization. With proper calibration, the loss in charge can be used to measure the amount of radiation to which the instrument is exposed. An external device may be used to measure the charge before and after exposure or the electroscope may be self-reading. In the self-reading type, the central electrode has connected to it a movable element (usually a plated quartz fiber). Since the charge on the fiber is of the same sign as that on the electrode, the fiber is repelled and moves away from the electrode. As the charge is reduced by the ionization the repulsion becomes less and the fiber moves back toward the electrode. The movement is a measure of the amount of radiation entering the instrument. The self-reading type are generally called "pocket dosimeters," and the non-reading type "pocket chambers." Either of these instruments may be made in the shape and size of an ordinary fountain pen and worn in the same manner.

CIVIL DEFENSE DOSIMETERS

CD V-138 Electroscope, gamma only (0-200 mr)
CD V-730 Electroscope, gamma only (0-20 r)
CD V-740 Electroscope, gamma only (0-100 r)
CD V-750 Electroscope charger

Photographic Emulsions

One of the earliest means of detecting radiation was by using a photographic plate. Properly prepared photographic emulsions respond to ionizing radiation in much the same way that similar emulsions respond to light, that is, by the formation of a latent image. The greater the exposure, the darker the film will be when developed. Beta radiation can be distinguished from gamma by shielding a part of the film with some material that the beta cannot penetrate. The amount of radiation to which the film has been exposed can be measured by developing it under carefully controlled conditions and comparing its "opacity" (degree of darkening) with that of exactly similar films exposed to known amounts of radiation. Monitoring radiation by means of photographic emulsions is inexpensive and sensitive. Film badges are small, light, and rugged, and therefore are easily carried. They can be distributed to large groups of individuals. Once developed, the film provides a permanent record of exposure which may be useful for medico-legal purposes. The main drawback to monitoring radiation by photographic emulsions is the time necessary to process the emulsion and the need for a standardized technique.

Chemical Indicator Solutions

The chemical reactions that result from ionization in certain solutions can be used to measure radiation. For example, a chloroform-water mixture, when exposed to radiation, produces hydrochloric acid in proportion to the radiation absorbed. An inherent drawback of chemical systems is the fact that their sensitivity to radiation is quite low. It requires approximately 25 r before any detectable chemical change is induced in any of the above systems. However, they may be used for measuring the dose from large sources of radiation or for civil defense monitoring purposes.

Glass Dosimeters

Certain special types of glass change properties when exposed to radiation. Silver-activated phosphate glass upon exposure to near ultraviolet light develops a luminescence proportional to the amount of gamma radiation previously received. This is the principle of radiophotoluminescence. Certain substances have the property of luminescing when exposed to ultraviolet light. This luminescence can be readily measured with the proper instruments. The minimum readable dose is about 10 r, with an upper limit of 600 r.

Neutron Dosimeters

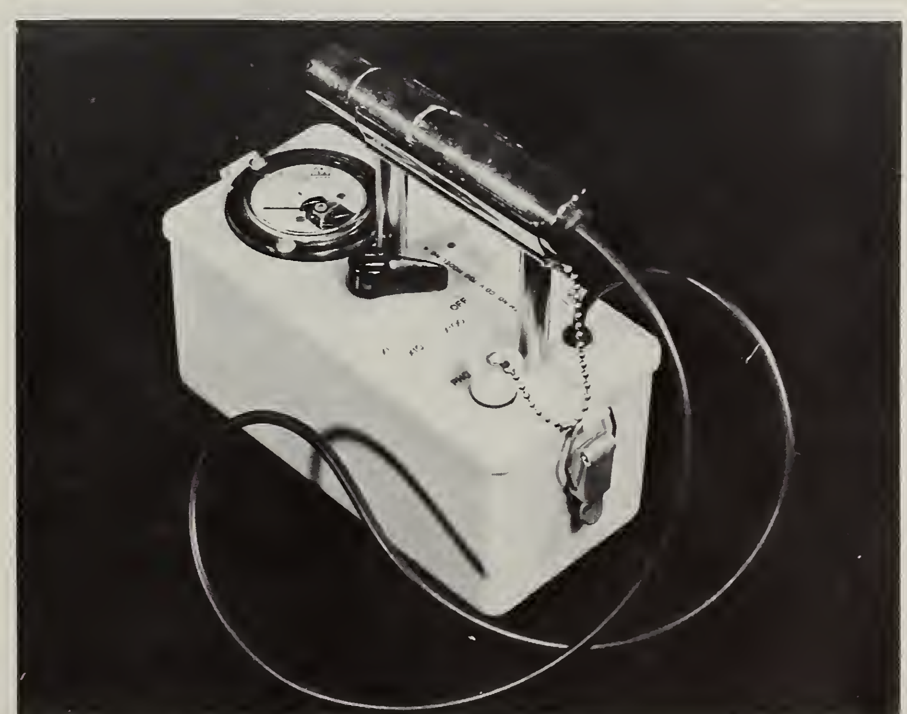
The determination of neutron radiation is important in testing nuclear weapons. Instruments used for this purpose depend upon the formation of radioactive isotopes when neutrons are captured by stable elements. Such substances as sulfur and gold will capture neutrons and develop induced radioactivity proportional to the neutron intensity to which they were exposed.

Summary

Personal dosimeters do not provide an exact index of the degree of radiation injury and must <u>not</u> form the sole basis for medical treatment; however, they may be

BN-10030X

Figure 22.—Personnel Monitoring Instruments (from left to right), DOSIMETER CHARGER (OCDM Item No. CD V-750); with two SELF-INDICATING DOSIMETERS (OCDM Item Nos. CD V-740 and CD V-730).



BN-10028X

Figure 23.—The Geiger-Mueller Instrument, RADIOLOGICAL SURVEY METER (OCDM Item No. CD V-700), showing its major components.

BN-10029X

Figure 24.—Ionization Chamber Instrument, MEDIUM RANGE GAMMA SURVEY METER (OCDM Item No. CD V-710).

BN-13626

Figure 25.—Ionization Chamber Instrument, HIGH RANGE BETA-GAMMA SURVEY METER (OCDM Item No. CD V-720).

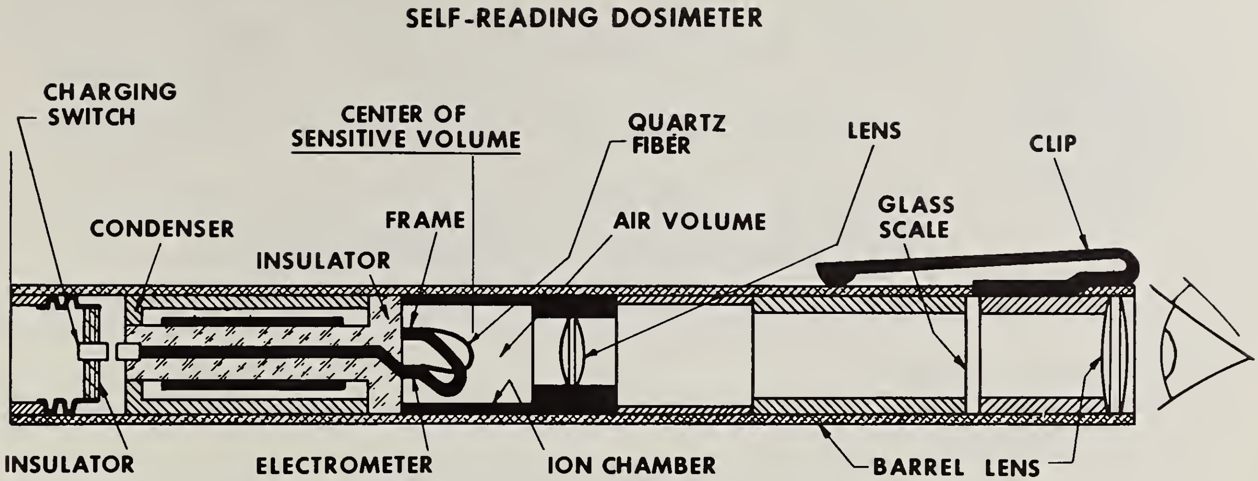


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Figure 26.—Self-reading dosimeter.

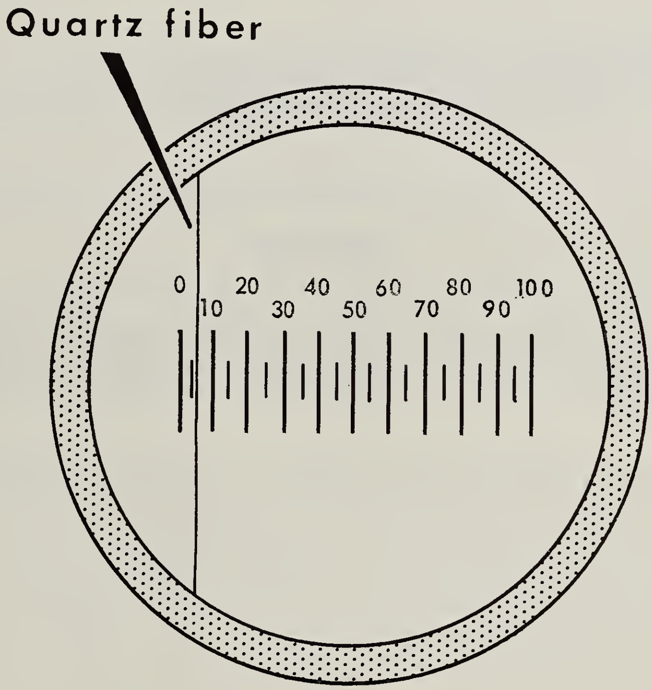

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Figure 27.—A diagrammatic sketch showing a reading on the glass scale of the self-reading dosimeter (OCDM item No. CD V-740).

of value in assisting in diagnosis, and in giving a person psychological assurance when he has not been dangerously exposed. They would be useful in indicating whether a person may perform emergency duties that involve additional exposure, in providing information for future diagnostic and therapeutic considerations, and in providing more exact scientific correlation between the degree of exposure and seriousness of the injury.

NOTE: Additional information on monitoring techniques and guides can be found in the section on National Damage Assessment. For information on the maintenance of radiological instruments issued to Federal agencies, see OCDM Advisory Bulletin No. 242 and Attachments A and B.

Questions

1. A Geiger-Mueller survey meter is used to measure:

   a. low-level radiation,
   b. high-level radiation, or
   c. all levels up to 50 mr/hr
   and is useful for (beta, gamma, beta-gamma) detection.

2. Electrometers are sensitive to (all levels, only high levels) of radiation. These instruments make (good, poor) dose-rate meters because they:

   a. have a sensitive electronic circuit,
   b. require two readings to evaluate the time factor, or
   c. are capable of indicating high level intensities.

References

(1) Civil Defense Information for Food and Drug Officials, 2nd Edition. Food and Drug Administration, U. S. Department of Health, Education, and Welfare (December 1956).

(2) Technical Bulletin TB-11-20. Office of Civil and Defense Mobilization (September 1955).

(COPY)

Executive Office of the President

OFFICE OF CIVIL AND DEFENSE MOBILIZATION

ADVISORY BULLETIN

No. 242
July 27, 1959

MAINTENANCE OF RADIOLOGICAL INSTRUMENTS ISSUED TO FEDERAL AGENCIES

I. PURPOSE

To provide procedures for maintenance of radiological instruments on loan or grant to various agencies of the Federal Government.

II. OCDM POLICY ON INSTRUMENT MAINTENANCE

A. Radiological instruments on loan or grant from OCDM to Federal Agencies may be repaired at OCDM Radiological Instrument Maintenance Shops. These shops and the Regional area to be served by each are listed on Attachment "A". This repair service will be available to all Federal Agencies, until such time as they are able to develop a maintenance capability.

B. To assist Federal Agencies in developing their own maintenance capability and assuming full responsibility for the repair of radiological instruments on loan or grant to them, OCDM will continue its current offer to train employees selected by a Federal Agency in radiological instrument maintenance. This will consist of shop training, either at Operational Headquarters, Battle Creek, Mich., or at one of the OCDM Radiological Instrument Maintenance Shops.

1. A Federal Agency requesting such training services will be responsible for salary, travel, and per diem expense of the employee while in training status.

III. INSTRUCTIONS FOR OBTAINING OCDM REPAIR SERVICE

A. The following procedure is to be followed in obtaining OCDM repair service for radiological instruments:

1. Ship instruments via most suitable transportation to the OCDM Radiological Instrument Maintenance Shop designated for the State in which you are located. (See Attachment "A".)

   a. Shipments must arrive at OCDM Radiological Instrument Maintenance Shops with all transportation charges prepaid by the Agency to which the instrument is on loan or grant.

   b. Return shipments will be C. O. D., unless arrangements are made in advance with the OCDM Radiological Instrument Maintenance Shops for other method of shipment, or for pickup.

2. Before sending an instrument in for repair it should be checked out according to the procedures outlined in Attachment "B".*

   a. This check may show that the instrument merely needs new batteries, or is being operated improperly.

   b. Replacement batteries shall be furnished by the Agency to which the instrument is on loan or grant. Batteries cannot be provided by OCDM as part of the repair services discussed in this bulletin.

3. It may not be possible to return the same instrument that is sent in for repair, or even to return the same model. Therefore, be sure to send along with each instrument all pertinent manuals and accessories.

4. OCDM will not be responsible for loss of instruments during shipment.

5. Box instruments carefully for safe shipment; and as a precaution against loss, put forwarding and return addresses inside the box, as well as marking them plainly on the outside of the box.

6. Shipment via parcel post is not recommended. Under the current shipping and handling procedures required by the Post Office Department, it is impracticable to provide the special handling necessary to assure against damage in transit.

7. Instruments will be returned from OCDM Radiological Instrument Maintenance Shops as soon as possible, but not later than 60 days after receipt.

B. Instruments improperly handled and maintained soon become irreparable. The following example, together with the remedial action that could have prevented the situation, is cited:

Situation	Remedial Action
Instrument battery compartment, chassis, and case became corroded and irreparable when batteries were left in the instrument over extended periods of storage.	Batteries should be removed from an instrument if it is to be stored more than a few weeks or not used for 30 days or longer.

* Attachment "B", Instructions for Checking Operability of Radiological Instruments, is not included. This can be secured from OCDM, Battle Creek, Michigan.

1. Instruments received at OCDM Radiological Instrument Maintenance Shops in irreparable condition because of improper care and maintenance, or because of damage resulting from accident, fire, flood, etc., will not be replaced.

   a. The Agency concerned will be so notified by OCDM and requested to furnish disposition instructions within 30 days. If these instruments were issued on a loan basis, the identifying number on Form OCDM (FCDA) 224 should be provided with the disposition instructions.

   b. If disposition instructions are not received within 30 days, irreparable instruments will be disposed of by OCDM and the number of instruments recorded as loaned or granted to an Agency will be correspondingly reduced.

2. To obtain replacement instruments, new requests must be submitted. New requests will be approved provided they are within the quota of instruments allocated to the Agency.

Leo A. Hoegh
Director

Attachment: "A"

ATTACHMENT "A"
Advisory Bulletin No. 242

OCDM RADIOLOGICAL INSTRUMENT MAINTENANCE SHOPS
AND REGIONAL AREAS SERVED

SHOP ADDRESS	AREA SERVED
Region I	
GSA/CDM Depot Rome Special Activities c/o Sampson Air Force Base Route 1 Romulus, New York	New York

SHOP ADDRESS	AREA SERVED
OCDM Warehouse Veterans Administration Supply Depot Somerville (Royce), N. J.	Connecticut Maine Massachusetts New Hampshire New Jersey Rhode Island Vermont
Region II	
OCDM Warehouse North Fifth Avenue Lebanon, Pa.	District of Columbia Delaware Maryland Pennsylvania
Shipping Address: Scioto OCDM Warehouse Lykens Road near Pole Lane Road Marion, Ohio Mailing Address: Scioto OCDM Warehouse General Delivery Marion, Ohio	Kentucky Ohio Virginia West Virginia
Region III	
OCDM Warehouse 440 South Front Street Rockwood, Tenn.	Alabama Florida Georgia Mississippi North Carolina South Carolina Tennessee Canal Zone Puerto Rico Virgin Islands
Region IV	
OCDM Warehouse West Hanover and Dobbins Streets Marshall, Mich.	Indiana Michigan Wisconsin
Shipping Address: OCDM Warehouse Crab Orchard National Wildlife Refuge, Area 7 Crab Orchard, Ill.	Illinois Missouri

SHOP ADDRESS	AREA SERVED
Mailing Address: OCDM Warehouse P. O. Box 67 Carterville, Ill.	
Region V	
Shipping Address: OCDM Warehouse Bastrop, Tex. (Railhead: Dunston)	Arkansas Louisiana New Mexico Oklahoma Texas
Mailing Address: OCDM Warehouse P. O. Box 196 Bastrop, Tex.	
Region VI	
OCDM Warehouse 1121 Fourth Street, S. E. Hampton, Iowa	Colorado Iowa Kansas Minnesota Nebraska North Dakota South Dakota Wyoming
Region VII	
OCDM Warehouse No. 931 Mira Loma Air Force Station Mira Loma, Calif.	Arizona California (Southern)
OCDM Warehouse 124 Keyes Street San Jose 12, Calif.	California (Northern) Nevada Utah American Samoa Guam Hawaii
Region VIII	
Shipping Address: OCDM Warehouse 1011 South Third Street Yakima, Wash.	Alaska Idaho Montana Oregon Washington
Mailing Address: OCDM Warehouse P. O. Box 402 Yakima, Wash.	

CALCULATING RADIATION DOSE RATES AND DOSAGE[1/]

Radiological monitors need more than just their ability to operate survey instruments to provide protection for themselves and others—and to determine the necessity, if any, for evacuation. Radiation injury or even death may depend upon accurate calculations of dose rates in the areas involved and dosages resulting from exposure to those rates.

Units of Measurement

It is assumed in this discussion that all radioactivity referred to is from mixed fission products found in fallout from a single bomb without overlapping patterns.

Dose Rate

Dose rate, or intensity, is usually measured in roentgens or milliroentgens per hour with a survey instrument. As radioactive fallout material accumulates, the dose rate increases; but after the fallout material has settled the dose rate begins to decrease due to the natural decay of the radioactive substances in the fallout.

Dose

Dose, as used here, is the total amount of ionizing radiation received. It is measured with a dosimeter. Dose is the product of the radiation intensity (dose rate) and the period of time exposed to that intensity. For consideration of the harmful effects of any particular dose, refer to the chapters on Biological Effects and Exposure Criteria.

Dose Rate Calculations (Past and Future Intensities)

Method 1 - "7-10 Rule".—The 7-10 rule is a very helpful and reliable rule of thumb. This rule is based on the fact that for every sevenfold increase in time following the detonation the dose rate decreases to 10 percent of the prior reading.

1/ Prepared by James D. Lane, Robert P. McCoy, and Robert A. Moody, Meat Inspection Division, Agricultural Research Service, and Kenneth J. Nicholson, Food and Materials Division, Commodity Stabilization Service, U. S. Department of Agriculture.

Example:

Future intensities

1000 r/hr - H + 1
100 r/hr - H + 7
10 r/hr - H + 49 (7x7) or 2 days
1 r/hr - H + 343 (7x7x7) or 2 weeks

As with many calculations, we can reverse the unknown:

Past intensity

1 r/hr - H + 343 (7x7x7)
10 r/hr - H + 49 (7x7)
100 r/hr - H + 7
1000 r/hr - H + 1

Method 2 - "Circular Calculators".—These calculators are sometimes called wheels or slide rules. They consist of 3 wheels, but only the outer 2 are used for dose rate computations.

The outer scale is black and refers to radiation intensities from 1/10 to 100K. The letter K is an extraction of the word kilo and means 1,000 times the unit measured; for example, 100K equals 100,000. The unit calculated may be either roentgens or milliroentgens; however, it is necessary to finish with the same unit used at the start of the calculation. Note that the figures increase in a clockwise direction. The middle wheel is red and refers to time, and has a scale range from 10 minutes to 5 years. The figures increase in a counterclockwise direction.

Example of use:

Assume the survey meter indicated an intensity of 100 r/hr at H + 1. Set the black number 100 on the outer wheel opposite the red 1 hour indication on the middle wheel. Do not change wheel positions, but instead hold the 2 wheels in position with the thumb and then by glancing up or down the scale obtain all past and future radiation time intensity readings for this particular radiation field.

Suppose it is desired to determine the intensity of this field at H + 7. Moving in a counterclockwise direction from the red 1 hour figure to the red 7, on the outer scale the intensity is found to be 10 r/hr. Moving further in this direction, 2 days (48 hours equals 1 r/hr, approximately). Compare these results with those of Method 1. To determine a time at which a particular intensity will be reached, reverse the procedure. In this radiation field, look on the outer wheel to the 50 figure and by interpolation of the red scale determine that this intensity would be reached at 1.8 hours. To further illustrate, set the wheel for a field having a reading of 30 r/hr at H + 1. Assume we wanted to know when it would be 10 r/hr. Using the black figure 10 and transposing to the red scale, this intensity would be reached at H + 2-1/2 hours or 1-1/2 hours after H + 1.

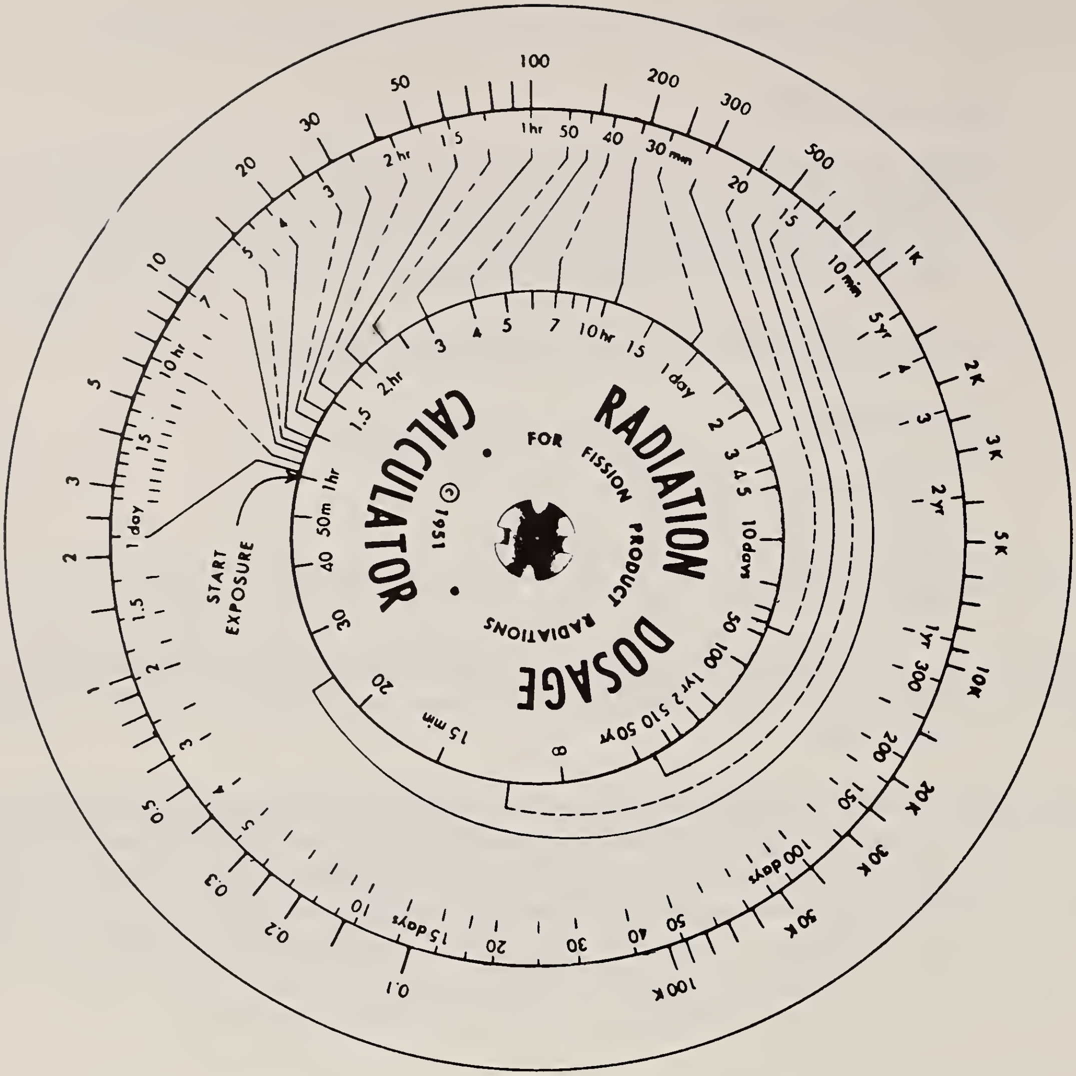

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Figure 28.—Circular calculator.

<u>Method 3 - Use of Charts.</u>- "Standard Curve".—A chart has been devised on which future intensities can be plotted on log graph paper. A "Standard Curve" has been plotted to show the relationship of time and intensity for mixed fission products (see Fig. 29 - Dose Rate Calculations.) This curve is based on the intensity of 1 r/hr at 1 hour following burst.

In order to plot any future or past intensity, find the point on the chart where the recorded intensity reading and time (after burst) intersect and draw a line through this point that is parallel with the "Standard Curve."

Example:

Suppose a reading of 25 r/hr were obtained 5 hours after the burst. What would be the calculated intensity at 10 hours after the burst?

Solution:

1 - Locate the 5-hour point on the horizontal axis (1) on fig. 30.

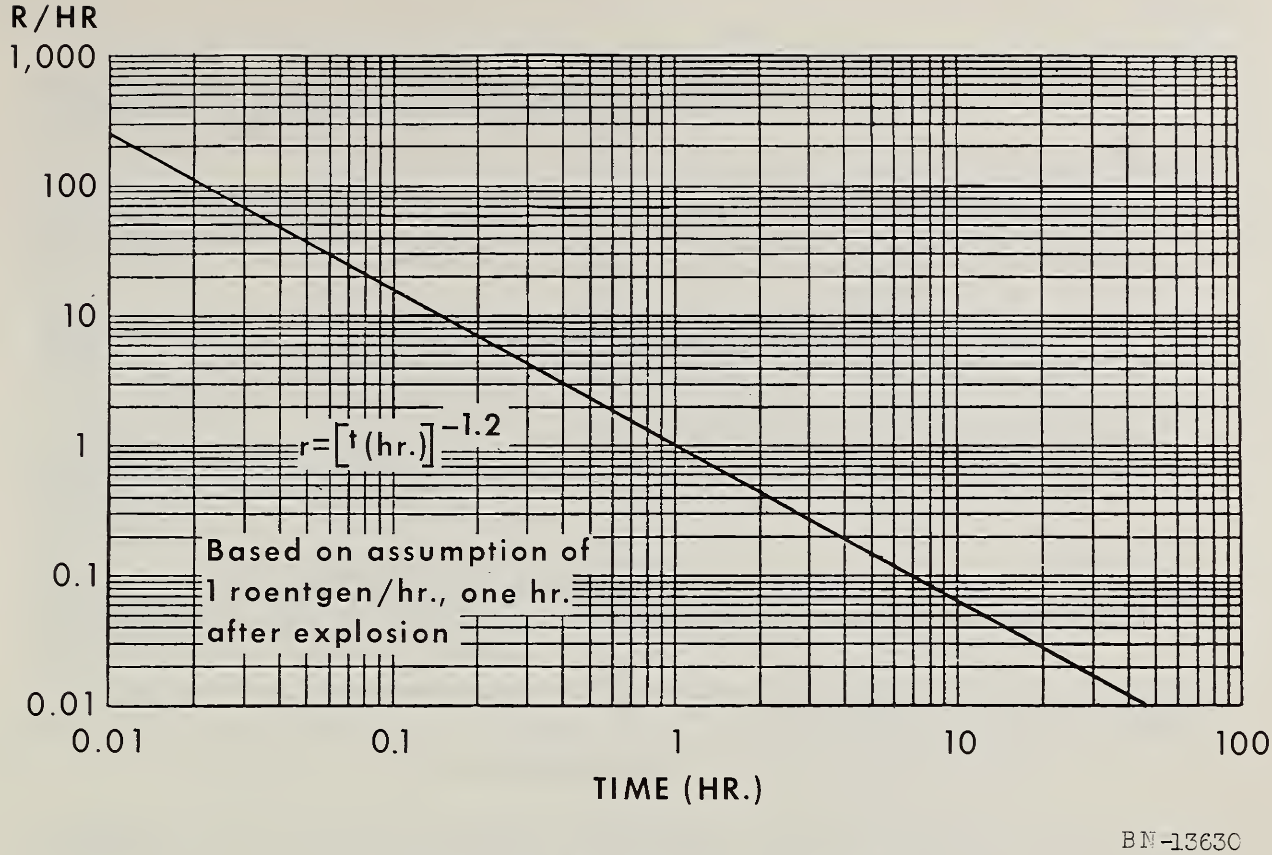

Figure 29.—Dose rate calculation.

2 - Follow the vertical line from the 5-hour point until it intersects with the horizontal line from 25-roentgen intensity (2).

3 - Through this intersecting point draw a line parallel to the standard curve line (3).

4 - Where this diagonal line intersects the vertical line from 10 hours, make a point (4).

5 - A horizontal line drawn from this 10-hour point to the left edge of the graph paper will designate the roentgens per hour at 10 hours.

6 - For this problem the answer should be 10 roentgens per hour at 10 hours following burst.

Dose Calculations

Method 1 - Rule of Thumb.—This method merely multiplies the intensity at the start of exposure by the number of hours exposed. This does not allow for radiation

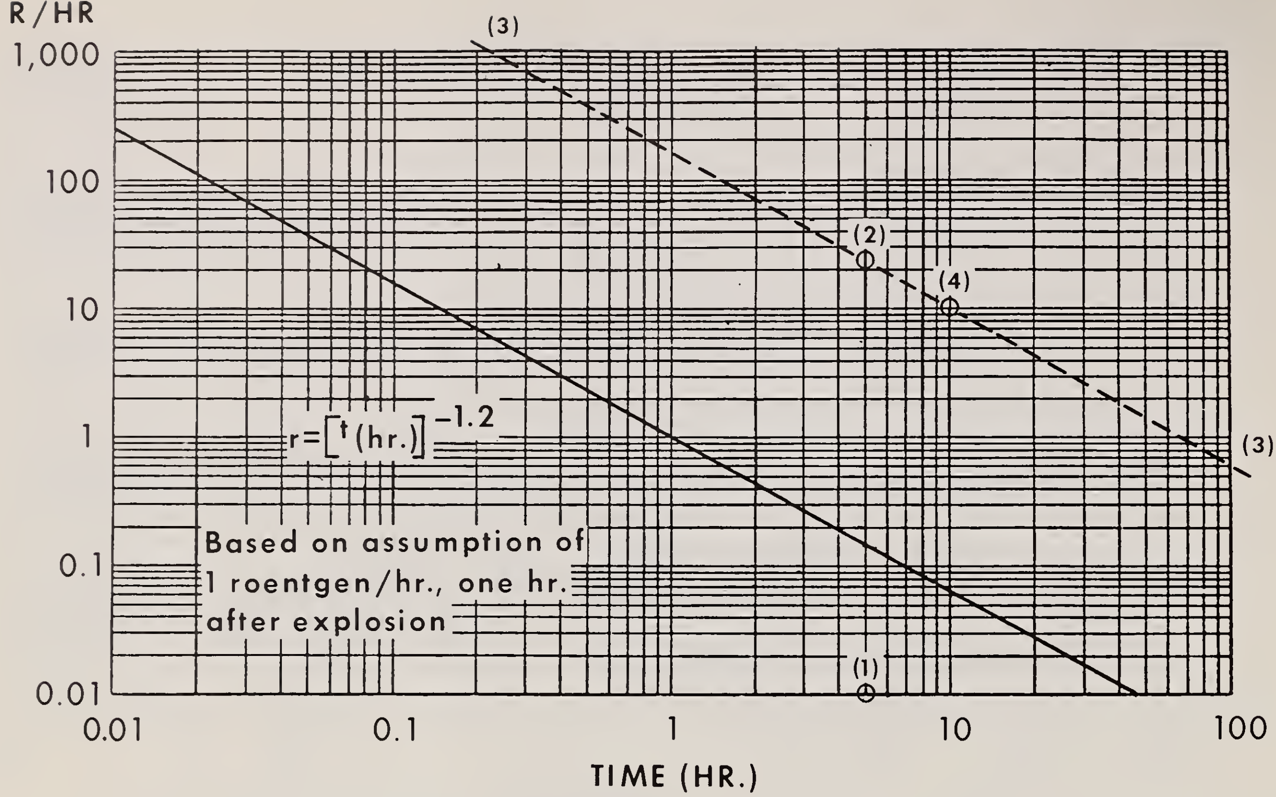

Figure 30.—Dose rate calculations.

decay and errs on the side of safety. The longer the time since the blast, the more accurate the estimation by this method will be.

Example:

A monitor enters a radiation field after all of the fallout has descended and the survey instrument reads 15 r/hr. He wants to estimate the dose for a 2-hour period.

Solution:

It will be somewhat less than 15 times 2, or a 30-roentgen dose.

Method 2 - F I T Rule of Thumb.—There is a special kind of dosage (total exposure) called infinite dose. This means the dose a person would receive if he entered a radiation fallout area and remained there forever. This infinite exposure could start with the arrival of the fallout or at a later time, the important thing for infinity dose calculations being that he remain and receive all the radiation that the fallout would emit. In this rule, the F is an unchangeable multiplying factor of 5, the I equals the intensity at the start of exposure, and the T indicates the time in hours after the bomb detonation.

Example:

The H + 1 intensity is 100 r/hr. Assume fallout arrived at H + 1. What would be the infinite exposure dose in this area?

Solution:

F (5) x I (100) x T (1) equals 500.

Example:

Determine the infinite dose for another man who entered the same radiation field at H + 7. Using our 7-10 rule of thumb, the intensity has now decayed to 10 r/hr.

Solution:

5 (this multiplying factor remains constant) x 10 (the new radiation intensity) x 7 (start of exposure) equals 350 r/the infinite dose.

In comparing the dosage between the different entry times, 150 r must have been received between H + 1 and H + 7. Indeed this is so, and in fact the F I T method can be used in this manner to determine dosage for a limited period of time.

<u>Method 3 - Use of the Circular Calculators</u>.—The use of the center wheel in conjunction with the 2 outer wheels is necessary for dosage determination. The center wheel has black figures and deals with time. The periods range from 15 months to 50 years and increase in a clockwise direction. Above the 50-year period observe what appears to be a figure 8 on its side. This indicates the infinite dose. The key to use of the center wheel is a red arrow on the middle scale marked "Start Exposure." Position the time of entry into the radiation field opposite this arrow. (See Fig. 28.)

Example:

The survey instrument indicated that fallout arrived at H + 1 and had an intensity of 100 r/hr. This field was entered at H + 1. What would be the accumulated dose at H + 7?

Solution:

Set the outer two wheels as previously instructed for this radiation field. Opposite the "Start Exposure" arrow, position the 1-hour black figure of the center wheel and with the thumb clamp all 3 wheels in position. Look down the scale to the 7-hour figure of the center wheel, follow the red line to the outer wheel and observe an exposure of 160 r. This compares favorably with the 150 r figure received in the solution of the F I T problem above. Now suppose the man who entered this radiation field in the same set of circumstances is to receive dosage of only 100 r. Having the wheel set in the same position, refer to the 100 r figure on the outer wheel, and follow the red line to the 3-hour figure on the inner wheel. The stay time would be 3-minus 1 hour (entry time H + 1) or 2 hours.

While the wheel is set for this radiation field, the infinite dose can be determined and, although it is a little difficult to interpolate, the answer should be around 500 r.

Method 4 - Use of Charts.—Presented here are the two graphs commonly used to compute the accumulated dose, both on log paper.

Fig. 31 is based on total dosage and an assumed intensity of 1 r/hr. There are three entries:

1 - A family of "time of stay lines."

2 - The horizontal axis representing "time after explosion."

3 - The vertical axis representing the ratio of the allowable dosage to the dose rate at H + 1.

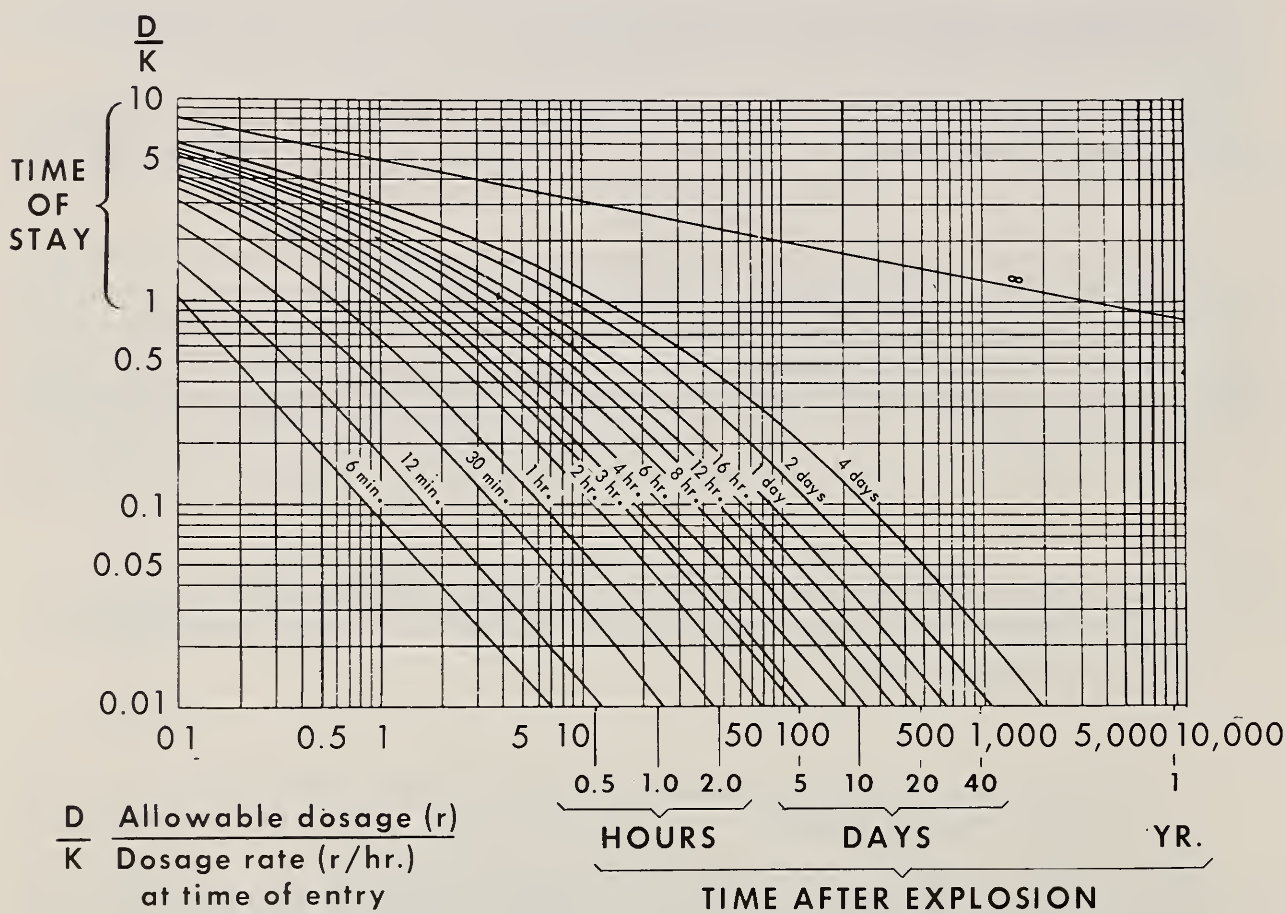

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Figure 31.—Graphical methods of computing accumulative dose.

Example:

At 8 hours after burst the dose rate is 50 r/hr. What will be the total dose received if a person enters the field at H + 8 and stays 6 hours, or until H + 14?

Solution:

1 - On figure 32, find the 8-hour point on the time-after-explosion axis (1).

2 - Follow this line until it crosses the 6-hour "time of stay" line (2).

3 - From the point of intersection, follow horizontally until the horizontal line intersects the $\frac{D}{K}$ ratio (3).

4 - This value is 0.3.

5 - $\frac{D}{K}$ equals 0.3 or D equals 0.3K.

6 - As stated in the problem, H + 8 equals 50 r/hr.

7 - Locate the 8-hour point on the horizontal axis, Fig. 33 (7).

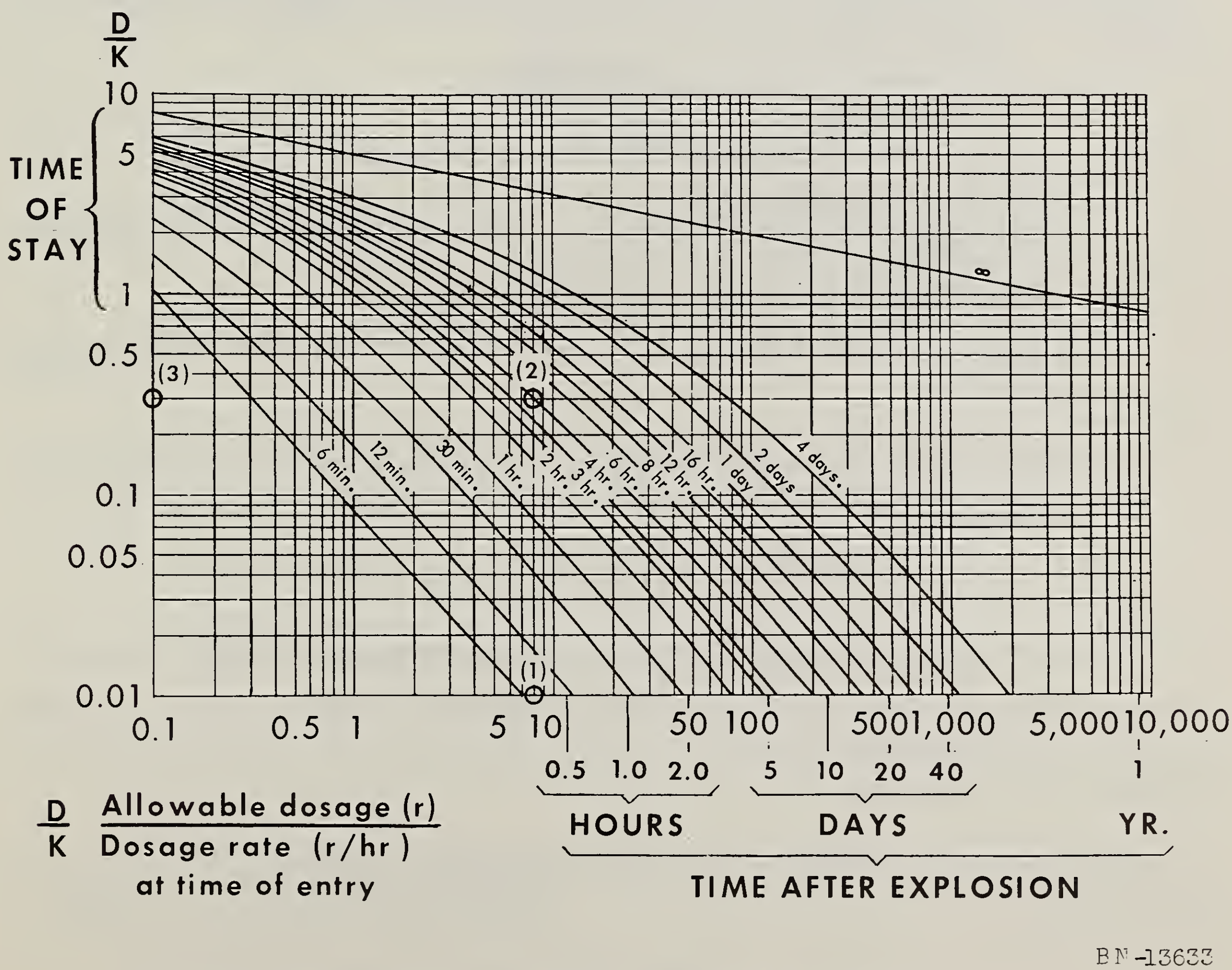


Figure 32.—Graphical methods of computing accumulative dose.

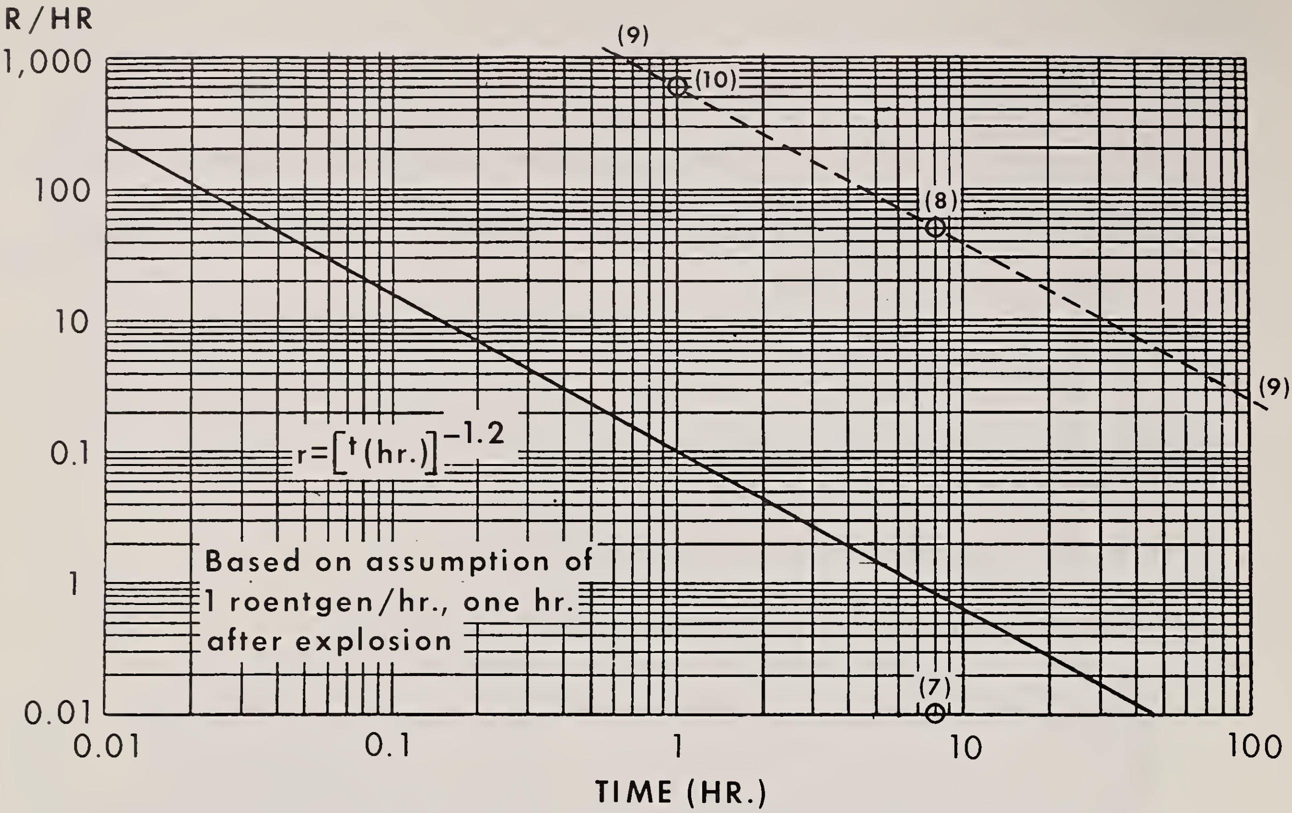


Figure 33.—Dose rate calculations.

8 - Follow the vertical line from the 8-hour point until it intersects with the horizontal line from 50 r intensity (8).

9 - Through this intersecting point, draw a line parallel to the standard curve line (9).

10 - Where this diagonal line intersects with the vertical line from 1 hour, make a point (10). The intensity is indicated as 600 r/hr at H + 1.

11 - Therefore, D (allowable dosage) equals (0.3 x 600) or 180 r.

Fig. 32 is another graph similar to Fig. 31 except that the vertical axis represents the ratio $\frac{D}{R}$ where D equals allowable dosage and R equals dosage rate at time of entry. Fig. 34 should be used exactly as Fig. 31, except that it is not necessary to calculate the intensity back to H + 1.

When using Fig. 34, find the $\frac{D}{R}$ ratio, then dosage equals $\frac{D}{R}$ ratio x intensity at time of entry.

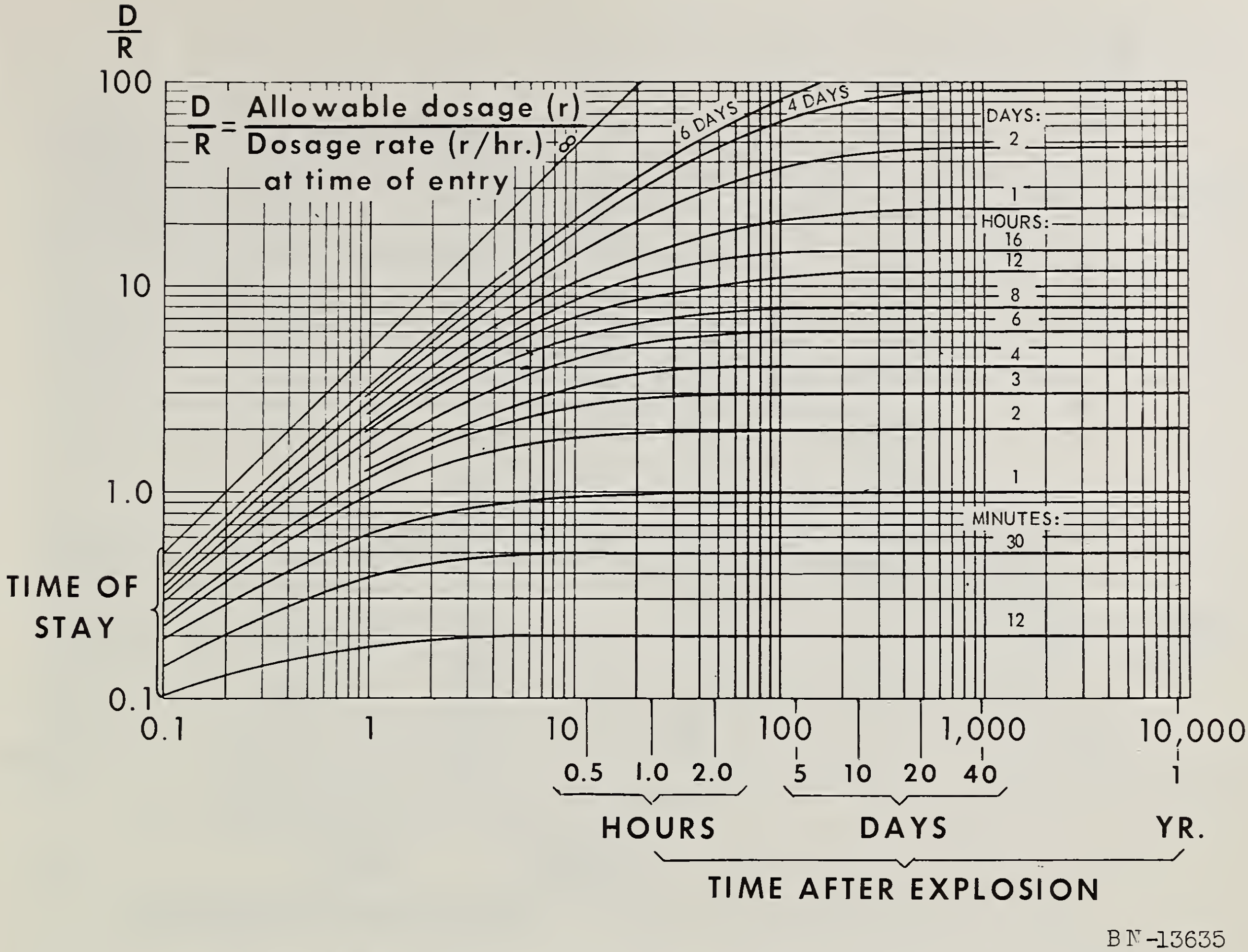


Figure 34.—Graphical methods of computing accumulative dose.

Example:

At 8 hours after burst the dose rate is 50 r/hr. What will be the total dose received if a person stays 6 hours or until H + 14?

Solution:

1 - Locate the 8-hour point on the horizontal axis on Fig. 35 (1).

2 - Follow the vertical line from the 8-hour point until it intersects with the 6-hour "stay-time" line and make a point (2).

3 - Follow the intersected horizontal line to the left. This value is 4 (3).

4 - The $\frac{D}{R}$ ratio being 4 or $\frac{D}{R}$ equals 4.

5 - Substituting the dose rate at the time of entry (H + 8 equals 50 r), the equation 4 equals $\frac{\text{Allowable dosage}}{\text{50 r (dose rate)}}$.

6 - Allowable dosage equals 4 x 50 or 200 r.

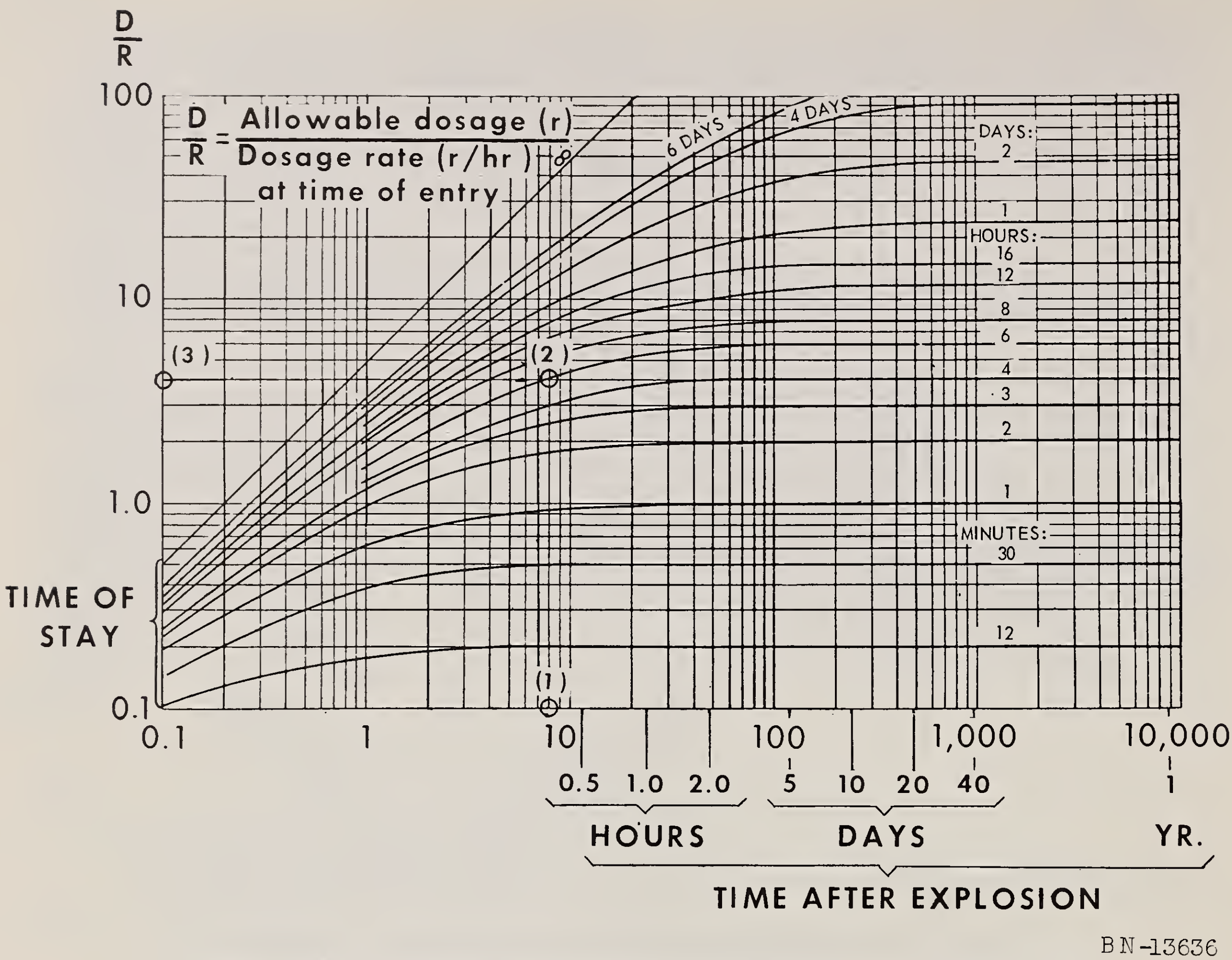


Figure 35.—Graphical methods of computing accumulative dose.

Summary

This chapter has outlined the difference between dose rate and dose calculations. Under dose-rate calculations the 7-10 rule of thumb, the use of the outer and middle wheels to determine past and future radiation intensities, and the use of charts have been discussed. In dosage calculations the use of a rough rule of thumb, the definition of infinite dosage, the F I T rule of thumb, the use of all 3 wheels of the radiation calculator to determine dosage, stay times, and infinite dose, and the use of charts for comparable calculations are explained.

Comparison of results computed by different methods will sometimes show variance. If correctly determined, the variance is of a level that would cause no operational concern.

Each calculation method presented will have advantages and disadvantages. For example, the wheel is unexcelled for ease in the computation of past and future intensities; but when an attempt is made to calculate the dose for a short period of time with the exposure starting after one day, too much interpolation is necessary. Here the graphs would be of more value.

The calculations are for planning purposes only. There is no substitute for at least one member of each group wearing an instrument that will measure the actual dosage received. As one gains experience in actual radiation fields, variations will be found that justify this premise.

Once the dosage is calculated, consideration must be given to attenuation (page 113 - does all the dose reach the body?) and exposure duration (page 114 - has the body had time to recover from part of the dose before receiving the balance?)

Questions

(1) The H + 1 intensity is 20 r/hr. What will be the intensity at H + 10?

(2) The H + 20 intensity is 3 r/hr. What was the intensity at H + 1?

(3) The H + 10 intensity is 5 r/hr. What will be the intensity at H + 15?

(4) The H + 1 intensity is 20 r/hr. What was the intensity at H + 1/2?

(5) The H + 1 intensity is 60 r/hr. We enter this field at H + 7 and stay 16 hours. (Please note that if we enter at H + 7 and stay 16 hours we will leave at H + 23.) What is the dosage?

(6) The intensity at H + 1 is 75 r/hr. When will the intensity be 5 r/hr?

(7) The H + 5 intensity is 60 r/hr. What dosage will we receive if we enter at H + 6 and stay 2 hours?

(8) The H + 7 intensity is 10 r/hr. What is the dosage when we enter at H + 6 and stay 2 hours?

(9) The H + 1 intensity is 50 r/hr. We desire to enter the field at H + 4 but our dosage is limited to 80 r. How long can we stay?

(10) H + 1 day intensity is 1,000 r/hr. What dosage would a man receive who entered at H + 24 and worked 4 hours?

Answers:

(1)	1.3 r/hr	(6)	9.7 hours
(2)	109 r/hr	(7)	80 r
(3)	3.1 r/hr	(8)	22 r
(4)	47 r/hr	(9)	2.9 days minus 4 hours
(5)	45 r	(10)	3600 r

ION CHAMBER SURVEY METER

FACE VIEW OF CD 710 MODEL L

Detonation time

12:30 P. M.

Local Time
6:30 P.M.

Location
____

Meter Reading
0.46 r/hr

Scale multiplier
10

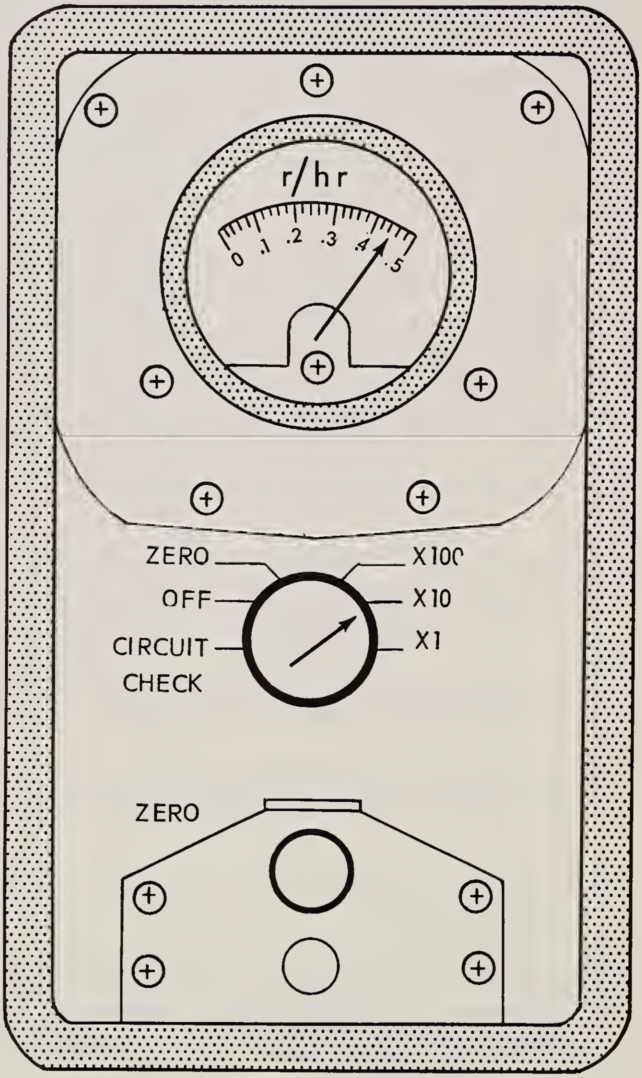
Rad. Int. Time of Rdg.
1. ______________ r/hr

Time of Reading
2. ______ H + ______ hr.

Rad. Int. H + 1 Hr.
3. ______________ r/hr

Rad. Int. H + 24 Hr.
4. ______________ r/hr

5. Rad. Int. H + ______ Hr.
1 r/hr



6. Estimate the dose received by the people or cattle in this area exposed in the open from H + 6 hours to H + 2 days - to H + 2 weeks.

7. Do the same as above assuming that they were in fallout shelters using reduction factors of 10 and 100, respectively.

8. Should people be removed from their homes in this area to a "safer" or "cleaner" area?

9. Will it be necessary to confiscate poultry and livestock in this area?

10. When will it be "safe" to work in the fields again?

NATIONAL DAMAGE ASSESSMENT[1/]

I. Definition:

Within the limits of our interests in food and agriculture, national damage assessment is a function which is being developed and led by the National Resource Evaluation Center[2/], an arm of the Office of Civil and Defense Mobilization, which in turn is a part of the Executive Office of the President. Under this leadership, the function involves all agencies of the Federal Government which have a responsibility for management of the resources of the Nation. Some staff agencies also are involved.

II. Function:

The primary function is to assure continuity of government for this Nation, regardless of severity of possible attack, and quick and effective mobilization of all resources remaining for the purpose of assuring that the effects of the attack are minimized, that the economy will operate at the highest possible rate, and that real income is rebuilt as rapidly as possible. This operation is part of the National Plan for Civil Defense and Defense Mobilization.

III. Scope of Damage Assessment Activities:

NREC uses a UNIVAC 1103A, one of the most powerful electronic computers available, to support its operations, but it also insists that a high level of manual capability be maintained for use in case the computer is down. The principles are the same for either method, but the volume of analysis possible within a short period of time is enlarged greatly by the computer.

A. Pre-Attack Activities:

Damage assessment capability is to be maintained by all the above-mentioned participants on both a pre-attack and a post-attack basis. Several activities are involved here:

1. Build Resource Library:

Pre-attack, attention is given especially to developing the lists of important resources by category, for example, flour mills.

2. Study Attack Effects on Availability:

Thereafter follows a study of the effects of assumed attack patterns against all such categories under a given weather condition, and under

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1/ Prepared by Kenneth J. Nicholson, Food and Materials Division, Commodity Stabilization Service, U. S. Department of Agriculture.
2/ Until late 1960 the NREC was known as the National Damage Assessment Center.

variable weather conditions. From such "attack" studies, probable "availability" for different time periods after attack is determined. With all pertinent resource categories examined, the defense planner then re-examines and redraws his plans for resource management post-attack.

3. Vulnerability Studies:

When this process of attack analysis is repeated many times for a given resource point or group of comparable points, using many attack patterns and many variations in weather, it provides a better basis for establishing the probability of any point suffering to any degree in case the Nation should be attacked. When applied to all points in a category, it becomes a "vulnerability study" for that category. Much pre-attack time is spent in this type of study, and it is a great aid in doing defense planning for post-attack use.

4. Developing New Methods and Filling Data Needs:

Of course, there is a constant search for improved methods of attack study, for doing actual assessment post-attack, and in adding to the other needed capabilities post-attack which have been mentioned above. In fact, this very training program—radiation monitors—is such an outgrowth.

B. Post-Attack Activities:

Post-attack responsibilities include at least two functions.

1. Assess the real losses and quickly build a picture of what the Nation has available to use and where it is, often by specific location and certainly by totals for metropolitan areas, by states, by regions, and for the Nation as a whole. This will be a very difficult job and will require much information from the field, including the very vital information on radiation which is to come from field monitors.

2. Resource management after attack is another vital function. The production and distribution process would be highly unbalanced by an attack and there would be a great draft upon all assessment officers, and especially upon the high speed computer for the purpose of trying to smooth out these imbalances so as to maximize national production and distribution with what remains.

IV. Methodology:

As for all work on which electronic computers are used, this process deals with Inputs and Outputs.

A. Inputs:

1. Resource Points:

Of major consequence here is the individual resource points that are vital to national survival. They represent all parts of the economy—civilian and military installations; government offices and relocation points; population, both human and livestock; transportation facilities, land, sea, and air; food resources and nonfood resources, etc., for a long list of categories. There are some 250,000 individual points in the NREC library, and more points are going in constantly. Something like 35,000 or 40,000 of these resource points will be for food or be directly related to food. All these resource points are located with all the precision possible or that is indicated by the importance of the category, often with an accuracy of 100 meters or less. However, such accuracy not always is possible and some points are represented merely by coordinates for the city or county in which the resource is located. Obviously a resource like cropland or livestock being widely scattered must be located by a central point in the group rather than an individual resource point.

2. Attack Pattern:

Matched against the resources are the weapons, which are assumed to be detonated within the area studied, usually just our states and territories, but often including adjoining areas as well, such as Canada, because of the fallout and other effects. Weapons are located with all the accuracy possible, preferably the exact center of detonation (GZ) being located to within 100 to 500 meters of accuracy. Weapon size and class by air or ground burst also must be read into the problem because each size and class has a different effect.

3. Weapon Effects:

Weapons yield and effect tables are read into the problem so as to be able to measure the effects of all sizes and types of weapons, usually measured in radii for a given effect for blast, direct radiation, and direct fire.

4. Weather Data:

Upper air wind direction and speed at various levels are important as indicators of where the fallout will be deposited. The NREC computer can use these data directly in calculations of H + 1 intensity for all points. Or, in lieu of this calculation, it is necessary to make a hand-drawn fallout map for the country, read its values by 10 km. squares and enter these readings into the computer.

5. Wild Fire:

Few fires set by a nuclear weapon would fail to develop into wild fires. The extent of such burn must be predicted (or observed) and

the damage measured and recognized in calculating total losses. Presently assessment of wild fire spread and loss measurement is done wholly by hand, but work is being initiated to lay the groundwork for subsequent programming of this function for machine handling.

B. Outputs:

Calculations made from the input data, again much the same whether by the high speed computer or by manual methods, produce the following:

1. Blast losses of resources, calculated as a function of over pressure to a given distance from ground zero. The system recognizes variations in blast effects, namely destroyed, severe, moderate, and light blast damage.

2. Fire losses that result from weapon bursts, either direct or as a result of wild fire.

3. Radiation effects, measured first in terms of intensity at H + 1 equivalent, arrival time of fallout and the Effective Residual Dose. These, then, are reflected into sickness and death losses and into denial time governing the future use of physical resources.

These outputs are the grist in the mill of damage assessment, and damage assessment becomes the base for all plans for resource management in an attack situation.

V. Importance of Adequate and Correct Radiation Information:

Most food and agriculture resources are relatively far from blast and fire areas when compared with other important national resources. Radiation would be the big killer of livestock and of the people who live on the land or who service agriculture and much of the food industry. Radiation is what would deny us use of land, deny us use of food, even much of that which is produced, and deny us access to food supplies in storage or to food processing and distribution facilities. This makes it extremely important in a post-attack situation that correct radiation information by specific location be available at all administrative levels, first for damage assessment and second for food management.

A. Actual Monitored Readings Replace Predictions:

No longer are the stylized fallout patterns of the pre-attack studies and exercises (Fig. 36) acceptable. They reflect a predicted or probable location, arrival time and intensity of radioactivity. Post-attack, the real situation must be sought out, plotted and read into all analyses and food management plants. Fig. 37, when compared with the first, shows how much a real fallout pattern may vary from a stylized pattern. This is the actual pattern laid down following one of the test shots in Nevada. True, this is a very small device compared to some of the weapons that might be used in an attack, and no one knows for sure that a larger weapon

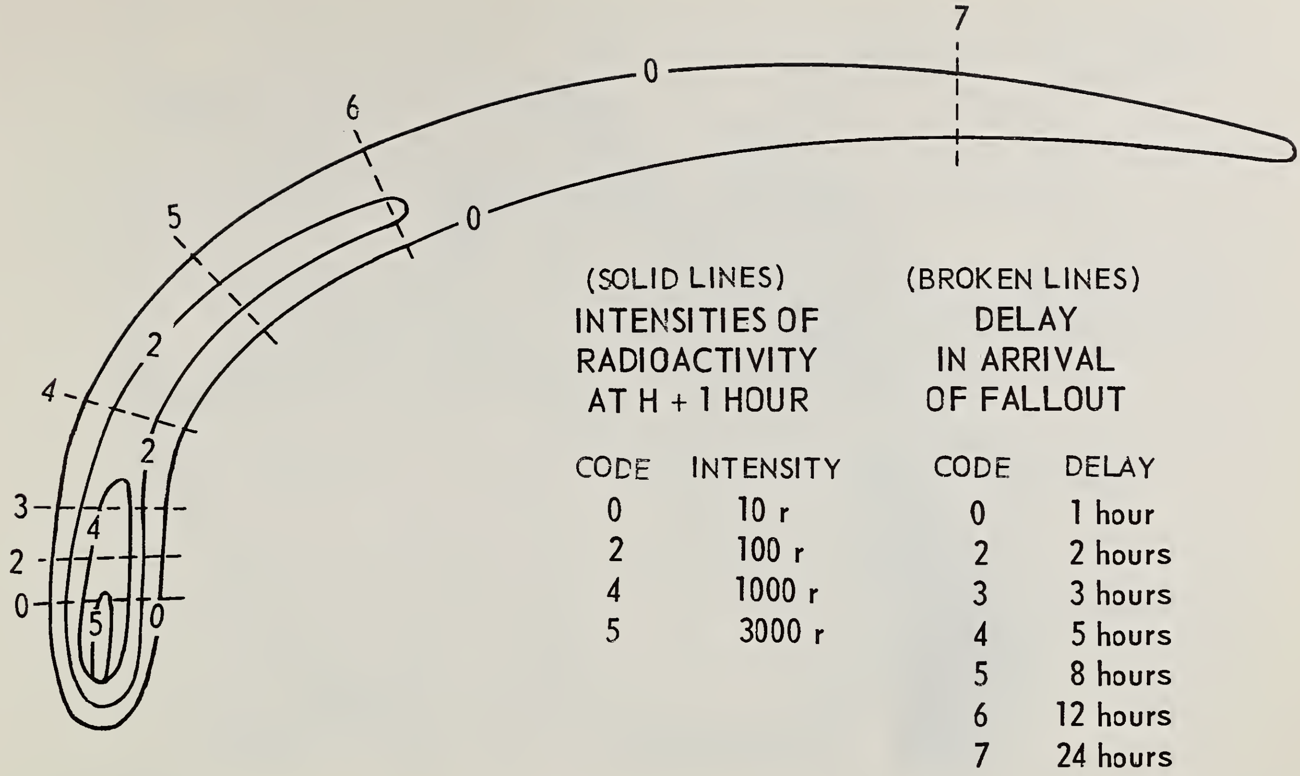

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Figure 36.—Stylized fallout pattern from an atomic explosion showing intensity and arrival times.

would lay down so many irregularities. However, all experts seem to agree that real fallout patterns will be more or less irregular in shape, and it will be hard to define the iso-intensity lines. Otherwise, there would be little justification in setting up a field monitoring network. Therefore, not only is it important to replace all possible "predicted" radiation information at the earliest hour with the highest possible number of field observations, but it is extremely essential that these observations be made and reported with all the accuracy possible.

B. Large Number of Observations Necessary:

On the first point above, bear in mind that in an attack situation, many monitors will be unable to report their radiation situation because of the high intensities they experience. This makes it extremely important that others in clean areas, or in areas of low intensity, move to the fringes and establish quickly the outside edges of all fallout patterns. This work, therefore, serves first to help save lives, and this is the Nation's greatest resource. Thus, its secondary functions become important.

C. Completion and Accuracy of Reporting:

On this second point, here are some guides mentioned by those persons who will need to use the monitors' reports.

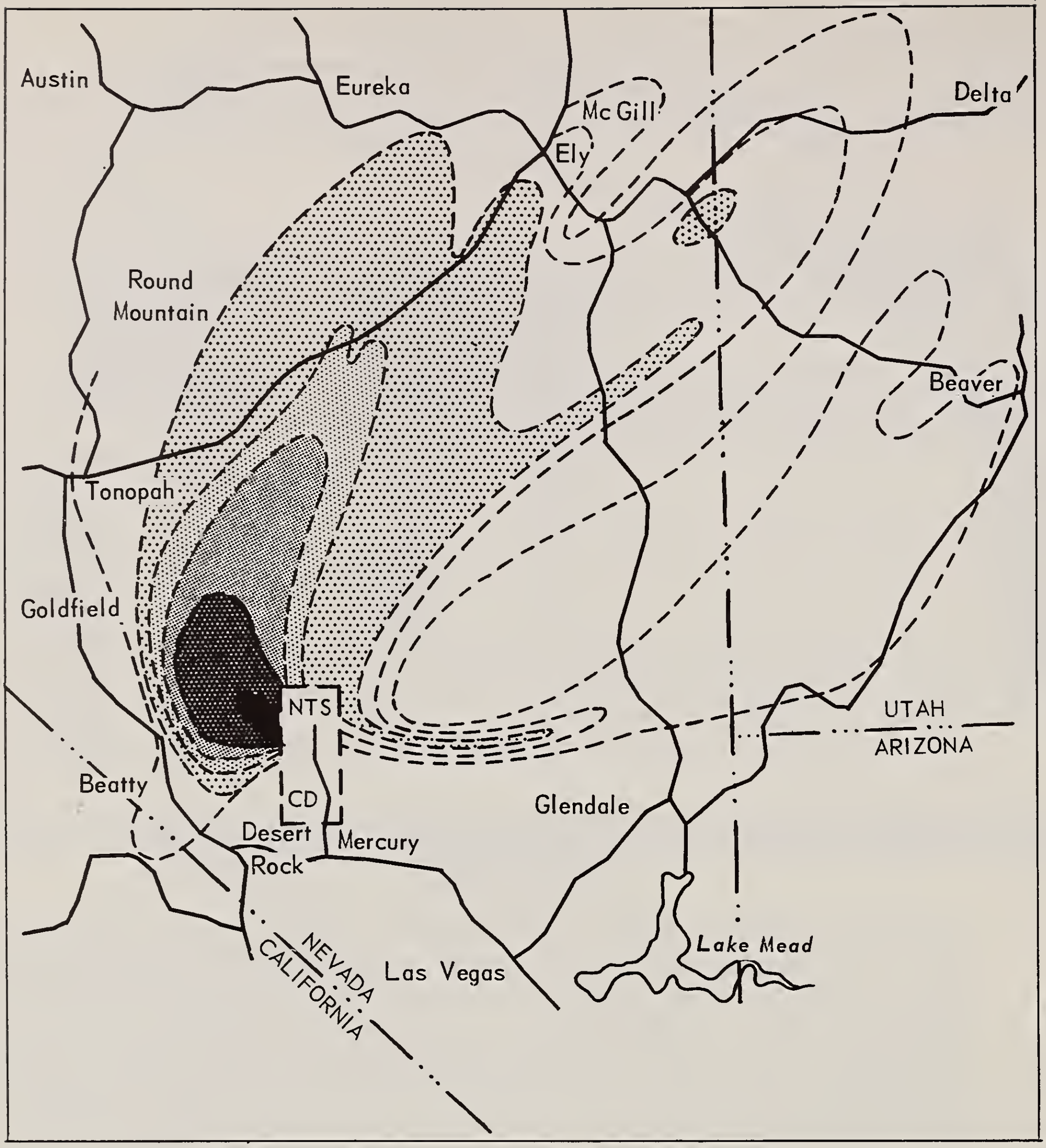

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Figure 37.—Actual fallout pattern.

1. There should be the least possible delay in making and reporting field monitors' observations.

2. Instruments should be maintained at a high level of performance so as to minimize errors of measurement. If known, the magnitude of error of measurement should be reported for each observation or the correction made before reporting the observed readings.

3. Each observation should be reported with point of observation indicated to a high degree of accuracy.

4. An "observation" should be an average of several "readings" taken within a very few minutes at a given point, using the same method for all readings but facing in different directions.

All observations should be reported, if known, in terms of exact elapsed time since the hour of detonation of the weapon which supplied the fallout for a given point.

5. Observations, made and reported before all fallout is believed to be down, should be accompanied by a statement to that effect.

6. Whenever possible, paired observations should be reported by all monitors for exactly measured time intervals, using identical locations, instruments, and methods of reading, thus providing a basis for verification of accuracy of other reports and the decay rate.

7. Fallout arrival time should be reported by location in all cases possible.

Possibly a complete list of such guides will be provided later to all monitors. These are mentioned here only to indicate the importance of a high level of performance by field monitors. Failure to observe such rules would cause many field reports to be useless until verified, and there likely will be little opportunity to request special reports from field monitors in an attack situation.

VI. Summary:

This Nation has provided a system for perfecting post-attack capability to assess the effects of an attack and thus to optimize management of remaining resources. Field reports indicating location and extent of radioactive fallout are essential to a proper functioning of this system, which is a part of the National Plan for Civil Defense and Defense Mobilization. USDA field workers are part of the team responsible for monitoring. Completeness and accuracy of monitoring and reporting operations are highly important for the saving of life, for the management of food resources, and other remaining resources in the Nation, and for assuring the continuity of a strong and effective government to protect the people and to serve their needs.

EXPOSURE CRITERIA AND DENIAL TIME[1/]

Permissible Dose

In order to safeguard the health of personnel who work with nuclear materials, their exposure to radiation over long periods of time is limited by imposing a maximum permissible dose of 3 rems per 13 consecutive weeks and a maximum permissible accumulated does in rems equal to 5 times the number of years beyond

1/ Prepared by Kenneth J. Nicholson, Food and Materials Division, Commodity Stabilization Service, U. S. Department of Agriculture.

age 18.These levels are established on the assumption that rate of occupational exposure maintained for many years should not involve extraordinary risks, but such levels cannot be considered applicable to emergency conditions.

It should be understood that this dose applies to absorption over the whole body, and for chronic exposures; that is, repeated and protracted exposures over long periods of time. Small areas can be exposed to very much larger quantities of radiation with no more than local injury being experienced. In addition, there is a difference between acute, that is, brief or occasional, exposure and the chronic exposure to which the tolerance limit applies. Thus, a dose of 5,000 r can be used to treat the small area of a skin cancer. Somewhat larger single doses may have unpleasant consequences, but will not prove fatal unless repeated at frequent intervals.

Civil defense authorities recognize that exposure to certain amounts of radiation will be accepted in some operational situations on a calculated risk basis along with other hazards of war. Trained medical personnel (radiological defense medical officers) will be responsible for evaluating the radiological situation in terms of human hazards and for advising civil defense authorities who must sufficiently appreciate the effects of radiation so that they will be able to utilize this advice in making operational decisions. The amount of radiation to be accepted in a specific situation must be based on operational requirements. With this decision made and radiological surveys completed, permissible periods for workers to stay in contaminated areas can be calculated.

The radiation dose that one should be willing to accept under emergency conditions depends upon what can be accomplished by such acceptance. While <u>all unnecessary exposures to radiation should be avoided</u>, relatively high exposures may be justifiable in rescue operations, in the restoration of critical facilities, or in the prevention of very large losses of property, supplies, and so forth.

Allowable Emergency Exposures to Radiation

Following in outline form is one guide for radiation exposure during <u>emergency</u> conditions. This guide was developed late in 1959 for use by civil defense authorities in case of extreme emergency only (reference 3, page 120), but was replaced before Operation Alert 1960, as seen from the discussion on page 105). The latter guide is based on short-range clinical effects only. It ignores possible long-range effects to the individual and genetic effects.

Exposure schedule not likely to result in loss of efficiency of emergency personnel.

- <u>Urgent Duty</u>

  Limit personnel to a one-time yearly accumulated net dose of 1,000 r with further restrictions of:

  - 30 r maximum net dose in first day of significant exposure.

- 200 r maximum net dose in first week of significant exposure.
- 230 r maximum net dose in any 2 consecutive weeks.
- In any event, a weekly net dose of 200 r should not be repeated short of a 2-month period.

Although individuals exposed to the above levels of radiation would be able to carry out assigned tasks during the year, they would still be damaged individuals, and they might suffer some general loss of vigor near the end of the year. Command decisions might prescribe different levels than those shown here, with different end effects.

- General Duty Indoors
    - 30 r maximum net dose in first day of significant exposure.
    - 200 r maximum net dose in 1 year.
- Residential Reoccupation and General Duty Outdoors
    - 30 r maximum net dose in first day of significant exposure.
    - 75 r maximum net dose in 1 year.

These values were to be exceeded only to avoid or minimize a greater hazard.

New Dose Standards, ERD Basis

For use in Operation Alert 1960, the OCDM adopted a new standard of radiation protection, this being based on the concept of limited recovery from radiation exposures that extend beyond the acute period, which is assumed to be the first 48 hours of exposure. The term Effective Residual Dose (ERD) is used to describe the net result of dose accumulation, less recovery, at the point where the rate recovery just equals the rate of further accumulation. While the older standards still may have further use under certain conditions, and are retained in this paper for that reason, the concept of ERD should be fully understood and considered in connection with human exposure to general radiation contamination, partly because it now is the basis for all human casualty calculations by the National Resource Evaluation Center, OCDM. It also is the basis for calculating Denial Time for contaminated areas, as indicated on page 106.

Under the new standards adopted in 1960, the maximum permissible exposure for "emergency" or "urgent duty" workers during an attack emergency is set at 200 r ERD, and for all other persons the maximum dose is 50 r ERD. The method used in calculating radiation dose, ERD basis, is explained on page 115.

Denial Time

This is a term used to describe the period of time persons would be prohibited, because of radiation intensity, from entering a contaminated area or leaving shelter in such an area. Also, the period of time croplands would be prohibited from use for designated agricultural products because of radioactive contamination, or milk prohibited from human consumption because of radioiodine content.

Denial time is calculated beginning with the detonation of the weapon that supplied the fallout for the area in question (or principal weapon if more than one is involved). This beginning time is spoken of as H hour. Factors important in determining denial time include:

- Intensity of the radiation field.
- Maximum permissible rate of dose accumulation.
- The attenuation factor applicable to the situation.

These factors are discussed below.

1. Intensity of the radiation field.—Others things being equal, the more intense the radiation in the area in which activity is desired, the longer the denial time must be before entry may be made, within the limits set on rate of dose accumulation. That is, if 30 r is set as the maximum dose to be permitted in a 24-hour period, much more decay must take place in an area where the intensity was 1,000 r/hr at H + 1 than if it had been 100 r/hr. In fact, it is about 8-1/2 days if H + 1 intensity is 1,000 r/hr and 28 hours if intensity is only 100 r/hr at H + 1. Both cases assume full outdoor exposure.

2. Maximum permissible rate of dose accumulation.—In addition to what has been said in the opening section on this subject, the following may be added. The most important point to note here is that "permissible rate" is a matter of relativity. This is usually spoken of as being in the realm of "command decision," the rate selected depending upon the several factors of the case being considered, for it should be recognized always that all radiation should be avoided to the maximum extent possible. The Federal Radiation Council has recommended against the use of "permissible" or "acceptable" dose as misleading in this area, and recommends instead the adoption of the term "Radiation Protection Guide," urging that all persons keep their exposure as far as possible below any guide that is established. In wartime, some exposures will be involuntary and many will be mandatory, depending upon the urgency of accomplishing desired objectives. The main question is "What will it cost in radiation exposure to obtain certain objectives dictated by the circumstances, and, do the benefits overweigh the costs?" Obviously, the "maximum permissible" rate must promise that the benefits will exceed the costs.

Several factors may be considered in establishing a "permissible rate of dose accumulation," including:

a. Urgency of the situation. Obviously, lifesaving is more urgent than salvage operations; salvage of medical supplies is more urgent than salvage of most machin-

ery; salvage of existing stocks is generally more urgent than initiating new production; and intiating new production with existing facilities is more urgent than rebuilding destroyed facilities. In view of the fact that all radiation is harmful, the less the urgency the smaller the acceptable dose.

b. The amount of time it requires to do a given task in a radioactive area or the period of time over which a given dose may be acquired.

A given dose of say 100 r is less harmful if taken over a long period than if taken over a short period. Therefore, a "permissible dose" usually is larger if it is to be taken over a week than over a day, and so forth.

c. The type of person (or animal) to be exposed. Most domestic animals can accept a larger dose than can man without showing radiation effects.

A standard often used in the past for determining the denial time to guide continuous occupancy of a contaminated area has been to stay out until the hourly dose rate (intensity) has fallen to 0.1 r/hr. This is roughly comparable to a dose of 1 r per day, after attenuation. This is a fair rule to keep in mind, for it is one which almost all people can use without nomograms, sliderules, or difficult mathematical formulae to calculate denial time. The so-called 7-10 rule can be used for this calculation.

Determining Denial Time by the 7-10 Rule

Time After Blast	Intensity in r/hr	Denial Time
H + 1 hr.	1,000	
H + 7 hrs.	100 approx.	
H + 49 hrs. (2 days)	10 approx.	
H + 14 days (2 weeks)	1 approx.	
H + 14 weeks	.1 approx.	14 weeks

Also, it is often useful to keep in mind that doubling the time after blast will reduce radiation intensity to 43 percent of its value in the first instance; i.e., if intensity is 1,000 r/hr at H + 1, it will be 430 r/hr at H + 2; or if it is 100 r/hr at H + 1 week, it will be 43 r/hr at H + 2 weeks. This, to be consistent, might be called the "2-43" rule. Using the 7-10 rule and the 2-43 rule, one can start with almost any value at H + 1 and calculate with fair accuracy the time when intensity will fall to any desired level.

These rules are inapplicable where there is overlap of fallout from weapons detonated at different hours or if the H hour is unknown.

It should be recognized, however, that this method of determining denial time has a basic weakness in that the level of intensity at time of entry should not be one level like 0.1 r/hr but should vary inversely with the intensity at H + 1. For instance, if intensity at H + 1 is low, say 1.0 r/hr, the rate will have fallen to 0.1 r/hr at approximately H + 7. So soon after detonation, decay is taking place at a rapid rate, and by H + 49 it will have fallen to 0.01 r/hr, so that the accumulated dose after H + 7 will be quite small. On the contrary, if intensity at H + 1 is 1,000

r/hr, it will not have reached the level of 0.1 r/hr until 3 months after detonation. By this time the stages of rapid decay have passed, and it will take 18 additional months to reduce the intensity to 0.01 r/hr, in contrast to the 48 hours indicated above. Dose accumulation after H + 3 months in this latter case would be more rapid than after H + 7 in the first case. Whereas only 2.6 r would be accumulated from H + 7 to H + 1 year for the first illustration above, the dose accumulation from H + 3 months to H + 1 year would be 260 r in the second illustration, even though both exposures started when intensity had fallen to 0.1 r/hr.

Therefore, it is suggested that this method of determining denial time be used only in an emergency and in lieu of more accurate methods. For example, in determining denial time for continuous occupancy of a contaminated area, it is recommended that workers use the method outlined on page 115 under the title "Denial Time," ERD Basis."

3. Protection factor applicable to the situation.—Normally, dose calculations are made on the basis of whole body exposure in an open field for a specified period of time. No shielding, of any type, is assumed. In actual practice, this situation would not prevail except under limited circumstances. Few persons would find themselves without shelter of some type, and this shelter provides "attenuation" or "protection." So in all cases of denial time calculation the "protection factor"[2/] must be calculated or selected so as to determine the proportion of a whole body, outside dose that actually is to be absorbed. The attenuating power of any shielding material is related to its density and thickness, whether it be air, wood, water, earth, concrete, steel, or lead.

The distance which the shielding material holds the radioactive material away also is an important factor. Therefore, the attenuation factor for a given building or shelter is usually a combination of the shielding value of one or more building materials (and possible of earth cover) and the distance between the outside shell and the person being shielded.

The thickness of various materials that will cut the radiation of an object by half (will provide a protection factor of 0.5) is as follows for several materials. Rough values for others may be calculated, if necessary, by use of their density values. This thickness is spoken of as the "half-value thickness" or "half-layer."

Material	Density	Half-layer
Air-about	0.08 lb./cu. ft.	300 feet
Wood-fir	34 lb./cu. ft.	17 inches
Water	62.43 lb./cu. ft.	9 inches
Earth	100 lb./cu. ft.	6 inches
Concrete	144 lb./cu. ft.	4.5 inches
Iron and steel	490 lb./cu. ft.	1+ inches
Lead	710 lb./cu. ft.	.33 inch

2/ "Protection Factor" is abbreviated P.F. Some persons prefer the term "Reduction Factor" (R.F.); others prefer the term "Attenuation Factor" (A.F.); others use the term "Shielding Factor." All have the same meaning. Some speak of a material as having a P.F. of 10, while others express the same concept with the decimal fraction 0.10. Both mean that the intensity of radiation behind the shield is but 1/10 the intensity to be measured in the open radiation field.

It should be noted that these thickness values are for the first half-layer and that as more half-layers are added the efficiency of the shielding materials increases significantly, as may be seen from the accompanying figure 38.

To give this information more practical application, Table 1, showing types of human shelters and associated protection and attenuation factors, has been included. Information for farm buildings is given in Table 2.

Also, it should be borne in mind that operation of a motor vehicle will provide some protection from radiation, the attenuation factor varying from about 0.33 to 0.75 for light trucks and passenger cars depending upon size and weight of the vehicle. Larger and heavier trucks will give even better protection.

Table 1.—Description of Shelter Categories with Associated Protection and Attenuation Factors1/

Shelter category	Protection factor 1/	Common examples2/
A-----	1,000 or greater. Better than 0.001	OCDM underground shelters. Subbasements or multistory buildings. Underground installations (mines, tunnels, etc.).
B-----	250 to 1,000 (0.004 to .001)	OCDM basement fallout shelters (heavy masonry residences). Basements (without exposed walls) of multistory buildings. Central areas of upper floors (excluding top 3 floors) of high-rise buildings3/ with heavy floors and exterior walls.
C-----	50 to 250 (0.02 to .004)	OCDM basement fallout shelters (frame and brick veneer residences). Central areas of basements (with partially exposed walls) of multistory buildings. Central areas of upper floors (excluding top floor) of multistory buildings with heavy floors and exterior walls.
D-----	10 to 50 (0.1 to .02)	Basements (without exposed walls) of small 1- or 2-story buildings. Central areas of upper floors (excluding top floor) of multistory buildings with light floors and exterior walls.
E-----	2 to 10 (0.5 to .1)	Basements (partially exposed) of small 1- or 2-story buildings. Central areas on ground floors in 1- or 2-story buildings with heavy masonry walls.

See Footnotes at end of Table.

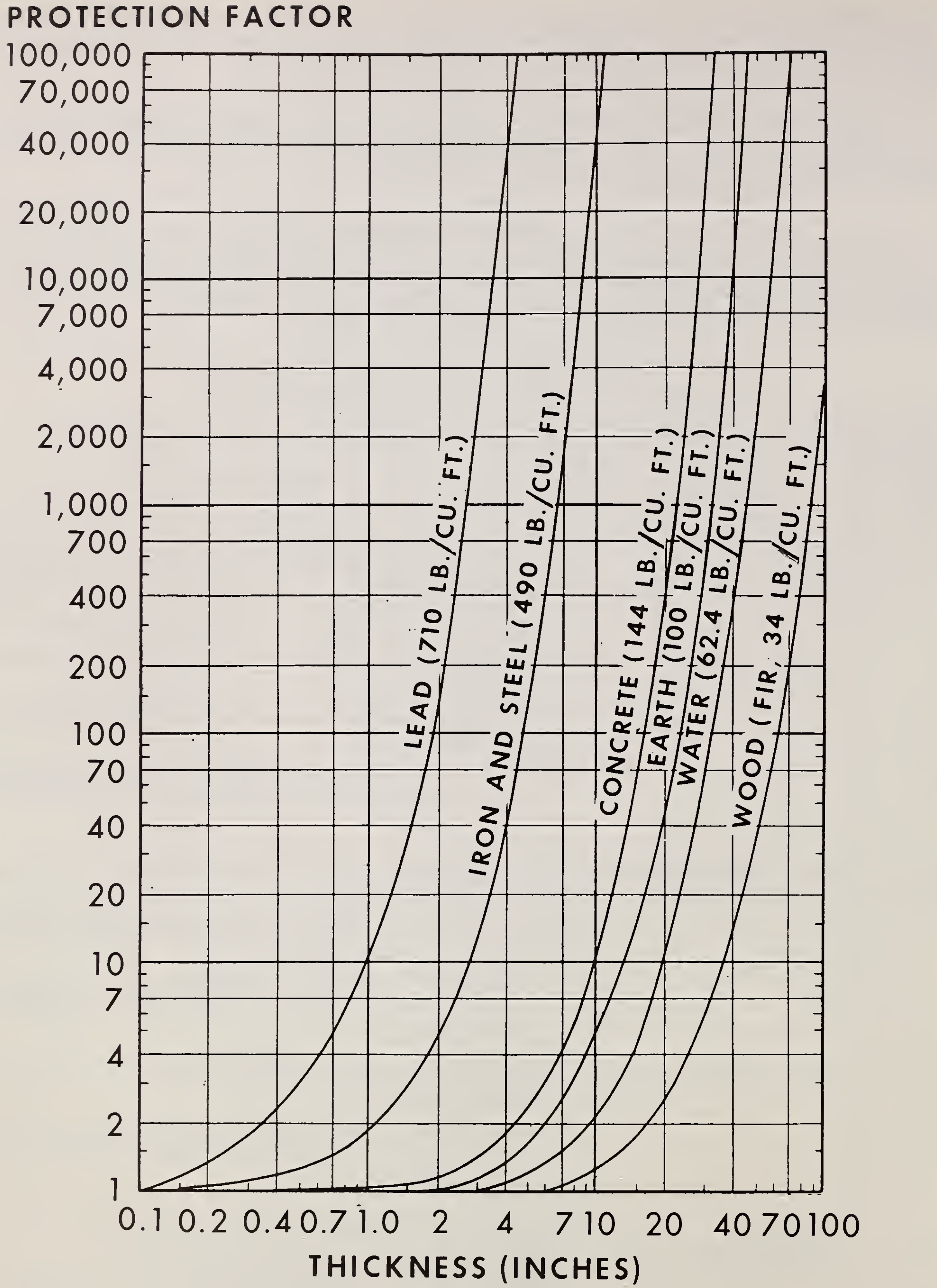

Figure 38. — Protection factors of shielding materials.

Table 1.—Description of Shelter Categories with Associated Protection and Attenuation Factors 1/ - (Cont'd)

Shelter category	Protection factor 1/	Common examples 2/
F-----	2 or less (0.5 or poorer)	Aboveground areas of light residential structures.

Source: Adapted from Appendix 2 Annex 10, National Shelter Plan NP 10-2, OCDM, May 1960.

1/This term expresses the relative reduction in the amount of radiation that would be received by a person in a protected location, compared to the amount he would receive if he were unprotected. The reciprocal of the protection factor is called the attenuation factor.

2/These examples refer to isolated structures.

3/For the purposes of this example, "high-rise" buildings are those greater than about 10 stories; multistory buildings are those from 3 up to about 10 stories.

Table 2.—Types of Buildings That Will Provide Approximately the Stated Attenuation for Loose-housed Livestock and Poultry 1/

Item	Attenuation Factor	Types of Buildings
1.	0.0125	a. Large barn (50' x 80' minimum); full bank on 3 sides; heavy monolithic wall on fourth side; few doors; and windows; 6 ft. baled hay 2/ above basement.
2.	.025	a. Large barn; half bank; monolithic foundation; few doors; and windows above animals' backs; over 12 ft. baled hay above.
3.	.05	a. Large barn; half bank, cinder block foundation; windows above cattle; 12 ft. baled hay.
		b. Large barn; gambrel roof; two-story on cinder blocks; no windows and few doors; full of baled hay (gambrel roofs retain less fallout than do gable roofs).
		c. As in 1.a. empty of hay.
4.	.075	a. As in 2.a. empty of hay.
		b. Full cinder block ground floor; 25 ft. baled hay.
5.	.1	a. Large barn; full masonry ground floor; no windows; empty.
		b. Large barn; one-half bank; cinder block foundation; 12 ft. baled hay.

See footnotes on page 113.

Table 2.—Types of Buildings that will Provide Approximately the Stated Attenuation for Loose-housed Livestock and Pountry[1/] - (Cont'd)

Item	Attenuation	Types of Buildings
6.	0.2	a. Large barn; full frame; no foundation sbove floor; 25 ft. baled hay.
		b. Hog house; solid concrete walls; no windows; metal roof.
		c. Poultry house; first floor only of large multistory masonry construction; windows 3 ft. above floor.
7.	.3	a. Medium size frame barns; no foundation above floor; 25 ft. baled hay.
		b. Very large frame barns; two-story; 2 ft. foundation, few windows, empty of hay.
		c. Full cinder block barns if empty, cinder block hog barns with metal roof.
		d. Large frame barn; one-half bank on cinder block, empty of hay.
8.	.4	a. Very large, all frame, two-story barn; empty of hay.
		b. Very large quonset type barn; full of confined stock.
		c. Larger sheep sheds, hog houses, and very large one-floor poultry houses; limited openings, full of confined stock.
9.	.5	a. Medium size barns with haylofts; frame; few windows; low foundations; empty.
		b. Barns in items 7 and 8 with asphalt or flatter roofs with high fallout retention.
		c. Cinder block or tile low poultry houses and hog houses, if asphalt roof or other retentive types.
		d. Larger one-floor poultry houses with limited openings.
		e. Midfloors of multistory poultry houses, including large frame barns converted to poultry houses.
		f. Any farm building giving shelter equivalent to first floor of a two-story frame dwelling with normal windows.

See footnotes on page 113.

Table 2.—Types of Buildings that will Provide Approximately the Stated Attenuation for Loose-housed Livestock and Poultry[1] - (Cont'd)

Item	Attenuation	Types of Buildings
10.	0.6	a. Very large "pole sheds," open on low side; animals confined under roof.
		b. Large poultry houses; one floor; numerous openings that can be covered with canvas.
		c. Smaller poultry houses with few windows.
11.	.7	a. Smaller poultry houses with considerable openings.
		b. Sheds on side of larger buildings, considerable openings; stock confined.
		c. Top floor of barn converted to multiple-floor poultry house.
12.	.8	a. Smaller sheds with large side open; animals confined.
		b. Smaller poultry houses and shelters; many openings.
13.	.9	a. Open sheds; animals free to run in shed or adjacent small lot only.
14.	1.0	a. No significant shelter - free running or grazing animals.

These values assumed loose housing of animals or poultry; animals confined in stalls near doors and low windows would have far less protection than would those in the most protected areas in the building.

1/ Based on calculations and guides provided by Mr. Neil Fitz Simons, OCDM.
2/ As shielding material, 6 ft. of hay are equivalent to 1 ft. of water or about 7 in. of earth.

Average Attenuation

Often it is necessary to know the average P.F. for a period of time during which personnel are living under a range of radiation intensity, or with variable shielding. This P.F. can be assumed to be merely a weighted average of the appropriate factors for the subperiods of time. Such a P.F. factor can be calculated as follows for a worker who is in a "hot area" where some shelter is provided.

Hours Spent Under Various Conditions	Protection Factor		Extension
4 hrs. - outside, no protection	1.0	=	4.0
2 hrs. - driving truck	.5	=	1.0
2 hrs. - driving light car	.75	=	1.5
2 hrs. - in basement of a frame dwelling	.4	=	.8
14 hrs. - in masonry building, away from windows	.05	=	.7
24 hrs. - variable exposure	?	=	8.0

Solving for the unknown: $\frac{8}{24}$ = 0.333, the average P.F. for the day.

This worker, if in an area where the average outside intensity of radiation is 0.1 r/hr for the day, is receiving a dose for the day of 0.8 r, approximately, for

24 hr. x 0.1 r/hr x 0.333 P.F. = 0.8 r/day net (approximately).

It is generally assumed that undisciplined activity of the average person will give a P.F. of about 0.67, i.e., the dose rate and net dose are reduced by about one-third. This factor would be too small for persons who are to spend most of their time outside and too large for the metropolitan worker who spends most of his time protected by steel, concrete, and brick.

It must be kept in mind that only the net dose received by the exposed person is pertinent in calculating denial time. Therefore, if a maximum permissible dose of 1 r/day is set as the standard for continuous living, this is the net dose after attenuation and not the gross dose that might be calculated from an instrument reading in the open. Therefore, if a P.F. of 0.333 is assumed, as was calculated above, and if the maximum dose is to be 1 r/day, people may occupy the area when the instrument reading is 0.125 r/hr, approximately, for

24 hr. x 0.125 r/hr. = 3.0 r/day gross dose x 0.333 P.F. = 1.0 r/day net dose. (This assumes no decay during the day, and since decay will take place, it adds to the safety of those exposed.)

Effective Residual Dose

Although the previous tools and methods have been in use for several years, it must be noted that in use, no recognition is made of the recovery factor in dose accumulation, except possibly in setting the "permissible doses" to be used in denial time problems.

However, during the winter of 1959-60, the National Committee on Radiation Protection and Measurements, after many months of study, recommended that henceforth all persons dealing with the problems of possible radiation from fallout adopt the concept of Effective Residual Dose. This charged them to recognize the recovery possibilities in the human body even under conditions of continuous exposure. Beginning June 1, 1960, all radiation casualty and denial time calculations by the National Resource Evaluation Center, OCDM, follow the Committee's recommendation. Therefore, all radiation workers concerned with fallout and its effects on sickness and death rates for man, or availability of resources in a fallout field, should have a good working knowledge of the concept of Effective Residual Dose, as explained here. For livestock, this concept has not yet been adopted.

This is the maximum effective dose of gamma radiation which a person will accumulate in a radioactive area after arrival of fallout (or after entry into an

established fallout zone) based on the assumption that biological recovery starts with the third day of exposure and continues at the rate of 2.5 percent per day until 90 percent recovery has been attained.

To determine ERD, multiply the intensity of radiation at H + 1 (after reduction for any attenuation received) by the indicated ratio (Table 2) for the hour when dose begins, whether that be on arrival of the fallout or upon entry sometime after fallout arrival. In formula this becomes:

ERD = 1 x P.F. x M, when

ERD = Effective Residual Dose

I = Intensity of Gamma Radiation at H + 1

P.F. = Appropriate Protection Factor, stated as a decimal fraction

M = The Multiplier Ratio from Table 2 for Each Possible Hour of Beginning Exposure.

Example: Intensity at H + 1, Protection Factor and Arrival Time are known; find ERD.

I at H + 1 = 1000 r/hr.

P.F. = 0.2

Arrival Time

= H+ 4

What is ERD?

Solution:

a. Determine the multiplier value for H + 4 from Table 3.

b. Substitute all values in formula and solve.

ERD = 1000 x 0.2 x 1.80

= 200 x 1.8

= 360 r

Denial Time, ERD Basis

The formula and table used in calculating ERD also are used in calculating gamma radiation denial time.

Operation Alert 1960 was conducted on the basis that an ERD above 200 r was excessive for URGENT DUTY workers, and doses above 50 r ERD were excessive for

Table 3.—Multipliers for Determination of Maximum Effective Dose, Gamma Radiation[1]/

Time When Dose Begins		ERD/I Multiplier
Hour	Day	
H + 1	D+	2.85
2		2.28
3		1.98
4		1.80
5		1.65
6		1.55
7		1.46
8		1.37
9		1.31
10		1.26
11		1.21
12		1.18
18		1.00
24	1	.90
30		.81
40		.72
48	2	.68
50		.63
60		.60
70		.56
72	3	.55
80		.51
90		.48
96	4	.47
	5	.40
	6	.37
	7	.34
	14	.23
	21	.17
	28	.14
	30	.13
	35	.11
	42	.10
	60	.080
	90	.058

Interpolate for intervening times and associated multiplier values.

1/ Supplied by Irving E. Gaskill, NREC, OCDM, November 1960.

OTHER PERSONS. These values are good for general use, but are subject to adjustment for specific situations. No person should accept more radiation than the urgency of the situation dictates.

This denial time calculation is based on the assumption that persons for whom the calculation is being made have no recent exposure to radiation; also that they expect to stay in the area for a period sufficiently long to permit their radiation dose to accumulate at least to an ERD level. Denial time for persons with recent prior doses would be longer than indicated by this calculation, while denial time for persons who not expect to remain in the area in question until they had accumulated an ERD could be shorter than is indicated by this calculation.

Denial time for persons who have no significant previous exposure may be calculated by solving for M in the formula, with the appropriate values for Intensity, Attenuation, and ERD substituted, then determining from the table of multipliers the permissible time of starting dose for this M value, as follows:

Example: What is the denial time for an area if I at H + 1 is 800 r/hr, average attenuation expected is 0.20, and maximum acceptable dose is 50 r ERD?

$$ERD = I \times P.F. \times M$$

Substituting:

$$50 = 800 \times .20 \times M$$
$$50 = 160\ M$$
$$M = \frac{50}{160}$$
$$M = .31$$

From the table of multipliers (Table 2) it is determined that for an M value of 0.31, dose must not start before about D + 9 days or ERD will be in excess of 50 r under the conditions of the problem.

Similar calculations would be made for any other stated level of maximum acceptable dose, provided it is stated as ERD.

A good and simple method has not been developed for determining denial time on an ERD basis for persons who have accumulated a significant dose before their period of essential activity within a contaminated area is begun. The most common example of this type is the person who is pinned down by early arriving fallout, necessitating a period of continuous stay in a shelter which does not give sufficient protection, before outside activity can begin, possibly for several days after arrival of fallout. An attack would leave many people in this situation, thus necessitating a method for calculating denial time for such persons. The exact method of making this calculation is too complicated for this paper, necessitating use of a more simple, <u>though less accurate method</u>. For such cases, a fairly accurate denial time can be derived if the ERD <u>under shelter</u> is subtracted from the "maximum permissible dose," and the remainder of the calculations completed as above.

Such calculations also require a knowledge of arrival time and the protection factor while under shelter. Assuming the fallout arrives at H + 4 and the shelter reduces the outside dose by a factor of 50 (P.F. = 0.02), the calculations are as follows:

$$ERD = I \times P.F. \times M$$

From Table 2, the multiplier (M) for an arrival time of 4 hrs., is 1.80. Substituting in the formula and solving:

$$\begin{aligned} ERD &= 800 \times 0.02 \times 1.80 \\ &= 16 \times 1.8 \\ &= 28.8 \text{ r } (29 \text{ r}), \end{aligned}$$

this being the ERD accumulated under shelter, and the value to be subtracted from the "maximum acceptable dose" of 50 r ERD.

This gives a new "permissible dose" of 21 r, which now is used in the formula for calculating DT, as follows:

$$\begin{aligned} ERD &= I \times P.F. \times M \\ 21 &= 800 \times 0.20 \times M \\ M &= \frac{21}{160} = 0.13 \end{aligned}$$

When M = 0.13, denial time, from Table 2, equals 30 days.

This compares with a denial time of 9 days for persons who can enter the area free of any radiation dose, as calculated on page 117.

It is seen, therefore, that a dose accumulated prior to starting essential outside activities can extend materially the time when those activities may begin safely. In fact, a poor shelter might permit a person to exceed the entire "permissive dose" while remaining continuously under shelter, thus creating an "infinite" denial time. In the above case, a P.F. of 0.04 would have resulted in an ERD <u>under</u> <u>shelter</u> of 58 r, which is in excess of the "acceptable dose" of 50 r ERD, thus leaving no opportunity for any outside activity, with its higher net protection factor.

Other Factors Bearing on Availability of Resources

In addition to denial for reasons fo radiation only as discussed above, there also may be other periods of denial before a facility or a resource can be relied upon for new production. There may be several factors contributing to this delayed use, but most important would be the time required to decontaminate and to rehabilitate a facility that has suffered either fire or blast damage. The time required for rehabilitation will vary with the facility and degree of damage and with the urgency of the situation, i.e., by whether "major effort" is expanded or not in the process.

The following gives some indication of the time allowance, on the average, <u>above</u> radiation denial time before facilities may be expected to be available for production after attack.

- Repairs of light damage comparable to heavy maintenance activity can be expected to proceed along with partial production. This would be classed as incidental rather than "major" effort. After 2 weeks of such activity it is assumed that light damage throughout the area would be sufficiently repaired to assure full capacity availability.

- The selective application of "major" effort to the repair of light damage may be expected to make such facilities fully available by the end of 1 week.

- Repair of moderate damage is so costly in manpower and material that it cannot be assumed necessarily to be available in sufficient quantity to effect repair of all moderately damaged facilities. Hence, the total capacity so affected can be considered to be available only selectively, at best. The repair period for those facilities selected for repair is assumed to average 2 months.

- All repair periods begin only as of the time of accessibility with respect to fallout radiation as shown herein. Major efforts to repair damage presumably would be preceded by major efforts to accelerate decontamination.

Questions

1. If a contaminated area after national emergency is to be continuously occupied, a person should not enter until the hourly dose rate has fallen to (0.01, 0.1, 1.0, 10.0) r/hr. This figure can be determined for an area of known H + 1 intensity by use of the 7-10 rule which states that:

   a. for each factor of 7 in time, the intensity of the radiation decreases by a factor of 10.

   b. for each factor of 10 in time, the intensity of the radiation decreases by a factor of 7.

   c. for each 7 hours after H + 1, the dose rate is 1/10 of the radiation intensity when the detonation took place.

2. The normal activity of an average person will allow one to use an attenuation factor of approximately (0.5, 0.67, 0.9) in calculating dose rate.

3. In peacetime, the maximum permissible weekly dose is (300 mr, 1 r, 230 mr) and a maximum permissible accumulated dose in roentgens equal to (50, 5000, 5) times the number of years beyond age 18.

4. Effective Residual Dose (ERD):

   a. is an old concept and is to be disregarded.

   b. is the latest accepted method of calculating casualty data and denial time for humans.

   c. is currently in use for both man and livestock.

References

1. The Effects of Nuclear Weapons. Prepared by the U.S. Department of Defense and published by the U.S. Atomic Energy Commission, June 1957.

2. Radiological Recovery of Fixed Military Installations, NRDL, NAV-DOCKS, TP-PL-13, August 1953.

3. Resource Availability Assumptions for Use with National Damage Assessment Center Facility Damage Computations, OCDM-NDAC, August 1959. (The present name of NDAC is National Resource Evaluation Center.)

4. Effects of Nuclear Weapons for use in National Readiness Planning, Office of Defense Mobilization, April 1958.

PERSONNEL PROTECTION[1/]

Protection from the effects of a nuclear weapon should not be regarded as a hopeless situation. Just the protection afforded by a foxhole 4 feet deep will insure survival for troops only 3,000 feet from a nominal size atomic blast. Protection thus afforded from flying missiles, burns, and initial radiation spell the difference between almost immediate death or survival for exposed personnel. It is realized that the shelter of a foxhole probably will not be available to the civilian population in event of nuclear attack, but the above fact is cited to demonstrate the effectiveness of even relatively light protection against the effects of nuclear weapons.

In addition to the danger from the blast, heat, and initial radiation experienced during the first few seconds following a nuclear detonation, the effects of residual radiation brought about by radioactive fallout presents a problem of much longer duration. So here, each phase will be discussed in turn and the most effective measures to counteract or control the dangers will be brought out.

Blast

Blast, or shock wave, as it is often called, results from the almost instantaneous expansion of gases in the super-heated fireball of an atomic explosion. This gas expansion results in extreme compression of the air or water surrounding the fireball and the consequent moving out of this shock front in all directions from the blast center. The shock wave moves approximately with the speed of sound and diminishes as it travels outward until eventually it is dissipated in the air or water.

1/ Prepared by James D. Lane and Robert A. Moody, Meat Inspection Division, Agricultural Research Service, U. S. Department of Agriculture.

Blast injuries depend upon many factors. Some important factors are the rise and duration of the blast pressure pulse. Generally, humans are more resistant to slowly rising overpressures of short duration than instantaneously rising overpressures of long duration.

The threshold for blast casualties are in the 15 pounds per square inch (p.s.i.) range for nuclear detonation above the kiloton range.

In a 1-megaton nuclear bomb, the shock front, behaving like a moving wall of compressed air, is some 3 miles ahead of the fireball after a lapse of 10 seconds when the fireball has attained its maximum size. At 50 seconds after the explosion, when the ball of fire is no longer visible, the blast wave has traveled about 12 miles.

Damage

Approximately 50 percent of the energy of the explosion is released in blast and the extent of the resultant damage is a function of the weapon size. As an example, a nominal sized weapon (20 kiloton bomb) will cause almost complete destruction out to a radius of one-half mile. A 10-megaton weapon will cause similar destruction out to approximately 4 miles. Light damage to buildings, such as broken windows and cracked plaster, will extend to 8 miles from ground zero from a nominal weapon explosion, or to 16 miles from a 10-megaton weapon.

Injuries

Injuries to personnel resulting from the blast include wounds resulting directly from the blast, or shock wave, and those resulting from secondary effects of the blast (collapse of buildings - flying debris). Direct-blast injuries probably would be relatively few in number. They were not common in the Japanese bombings. The largest group by far would be the indirect type, and they would include all types of injuries, with a high percentage of them owing to flying glass or other missiles.

Protection

As with all the hazards of an atomic explosion, distance from the point of detonation is of most value. However, if evacuation of a target area is not possible, emergency protective measures can be taken. Subways in the larger cities and subbasements in business buildings, or any other underground structure, would provide emergency protection. However, even the basement of a reinforced concrete or steel building is not an adequate substitute for a well-designed bomb shelter.

In a surprise attack, where there is no opportunity to take shelter, immediate action could mean the difference between life and death. A person inside a building should immediately fall prone and crawl behind or beneath a table or desk. This will provide a partial shield against splintered glass and other flying missiles. No attempt should be made to get up until the blast wave has passed, as indicated possibly by the breaking of glass, cracking of plaster, and other signs of destruction. The sound of the explosion also signifies the arrival of the blast wave.

A person caught in the open by the sudden brightness due to a nuclear explosion should seek a shelter of some kind (doorway, tree, ditch, trench) if it can be reached within a second. Otherwise, he should drop to the ground and curl up to protect his face, arms, and body as much as possible.

Heat

In addition to blast, which utilizes about 50 percent of the energy released in a nuclear explosion, heat or thermal radiation is also released and accounts for approximately 35 percent of the released energy. This thermal energy is in the form of electromagnetic energy and is liberated as infrared, ultraviolet, and visible light. It travels with the speed of light.

At the detonation of a nuclear weapon, the large amount of energy released as thermal energy raises the temperature of the fireball to several million degrees, which approaches the temperature of the interior of the sun. This temperature is so great that the fission products, bomb casing, and other weapon parts are converted into gaseous form, and the temperature at ground zero may reach 3,000° to 4,000°C. or higher, depending on the size of the weapon and its proximity to the ground. This temperature falls off rapidly with distance, but it can produce effects several miles from the point of detonation.

Damage

Although blast is responsible for most of the destruction caused by a nuclear air burst, thermal radiation contributes to the overall damage by igniting combustible materials, e.g., finely divided or thin fuels such as dried leaves and newspapers, and thus may start fires in buildings or forests. These fires may spread rapidly among the debris produced by the blast. Heavier materials, such as wood more than one-half inch thick, plastic, and heavy fabrics, char but often do not burn. Dense smoke, and even jets of flame, may be emitted but the material does not sustain ignition.

It is obvious, however, that where combustible materials are sufficiently close to an atomic explosion, as will be the case if a city is bombed, fires will be started. As the shock wave follows the heat wave after the first fraction of a second, it will generally extinguish the initial fires, and the secondary effects—broken wires, wrecked furnaces, etc.—following the explosion will more often be responsible for later fires. The destruction caused by the blast creates a situation where fire can spread rapidly and will generally prevent any effective attempts to extinguish it. This uncontrolled conflagration may produce a fire storm, creating strong upward drafts above the fire and strong winds from all directions on the surface inward towards the fire.

Injuries

Thermal radiation can cause burn injuries either directly (by absorption of the radiant energy by the skin) or indirectly (as a result of fires started by the radiation

or blast.) The direct burns are often called "flash burns," since they are produced by the flash of thermal radiation from the fireball. The indirect (or secondary) burns are referred to as "flame burns." They are identical with skin burns that would accompany any large fire no matter what its origin. However, from the point of view of their overall effects on the body and their treatment, flash burns and flame burns appear to be similar.

One of the most striking facts connected with the nuclear bombing of Japan was the large number of casualties due to flash burns caused by thermal radiation. The situation was aggravated by the fact that the atmosphere was very clear and that the summer clothing being worn was light and scanty. It has been estimated that 20 to 30 percent of the fatal casualties at Hiroshima and Nagasaki were due to flash burns, as distinct from those who suffered from flame burns. Thermal radiation burns were recorded at a distance of about 2-1/2 miles from ground zero at Nagasaki and at a somewhat shorter distance at Hiroshima. As might have been expected, the incidence of flash burns was less with an increase in distance from the explosion.

Protection

The intervention of any shadow-producing object decreases the extent of injury from thermal radiation. In a building, emergency shelter may be taken anywhere, away from windows of course. Outdoors, some protection may be obtained in a ditch or behind a tree or utility pole. Probably the best instinctive action in any emergency situation is to drop to the ground in a prone position, behind the best available shelter, using the clothed parts of the body to protect the hands, face, and neck.

As a general rule, at least two layers of clothing are desirable to provide reasonable protection against thermal injury. The outer garment should preferably be of a light color to reflect a portion of the heat and the clothing should be loosely draped, to provide adequate air spaces between the layers and between the undergarments and the skin. Suitable treatment of fabrics, especially dark-colored materials, to render them flame resistant, would be advantageous.

Initial Radiation

Initial or "prompt" radiation consists mainly of gamma rays and neutrons and accounts for approximately 5 percent of the energy of a typical nuclear blast. Both of these, but especially the gamma rays, can travel great distances through the air and can penetrate even considerable thicknesses of material. These radiations can be neither seen nor felt by human beings but can have harmful effects even at a distance from their source; hence, they are an important aspect of a nuclear explosion.

These initial nuclear radiations are produced within the first minutes or so following the explosion and are the result of (1) neutrons that are released at the moment of detonation, (2) gamma rays from inert materials that capture neutrons and become radioactive, and (3) gamma rays from the decay of the fission products for approximately 1 minute. Fission products also emit beta particles and the unused atomic fuel

releases alpha particles but since these have limited ranges they are of no practical significance in the initial radiation.

The instantaneous gamma and neutron exposure experienced from a nuclear detonation depends upon the distance from the burst and the attenuation factors (generally, the more dense the air, the greater the attenuation). For large weapons the midlethal dose would probably not exceed 3 miles. For these large type weapons, however, the devastating effects of blast and thermal radiations far outrange the hazardous dose from prompt radiations.

Damage

Generally speaking, initial radiations are not considered harmful except to life. However, it is possible to produce induced radiation in normally stable material close to ground zero through the absorption of neutrons. This would create a hazard during salvage operations and must be considered in utilizing food, water, or drugs exposed to such neutron bombardment.

Injuries

Exposure to initial radiations produces much the same effect as does exposure to residual radiations or "fallout," as it is more commonly known. However, the gamma rays produced from a nuclear explosion are generally of a higher frequency than those encountered in fallout, and consequently are more penetrating. Thus, the problem of adequate shielding to protect personnel is greater in initial radiation.

Neutrons and gamma rays both injure by penetrating deeply into the body and ionizing the atoms that make up the various elements—carbon, nitrogen, hydrogen, oxygen, among others—so that the atoms are no longer neutral electrically, but carry a positive or negative electrical charge which makes them violently reactive chemically. Ionizing radiation disrupts the complex combinations of these elements and thus changes the proteins, enzymes, and other substances that make up our cells and bodies. As a result, the cells are injured or killed, and bodily functions can be affected. If enough cells are damaged or killed, a person becomes seriously ill or dies.

Results of Exposure

Clinical observations have shown that heavy external exposure to penetrating radiation causes a massive breakdown of the body's tissues, particularly in certain organs of the body. Lymphoid tissue, bone marrow, the sex organs, and the lining of the small intestine suffer heavy damage. Muscles, nerves, and fully grown bones are not so easily injured. Other tissues, such as skin, liver, and lung, lie between these extremes. However, unless the radiation has been extremely heavy, cells may not die for hours or days.

As an example of results from exposure to 400 roentgens, considered near the midlethal dose for man, the following symptoms are to be expected:

Phase I

Within an hour or so after exposure, the patient becomes nauseated, vomits, and suffers general prostration and weakness. Diarrhea may occur and the blood pressure may fall a little. In general, the heavier the dosage, the more severe the illness.

Phase II

After the onset of illness, symptoms tend to disappear, and for a period of a few days to several weeks the patient feels less ill. This period will be short in patients who have suffered heavy radiation.

Phase III

The illness reaches its height during this phase. Whether or not the patient survives depends on his ability to endure this acute stage. The patient becomes apathetic and develops a fever and rapid heart action. He becomes increasingly weak and loses weight. He loses his appetite, may become nauseated, and suffer severe diarrhea, which is sometimes bloody. Small hemorrhages may appear in the skin and the gums bleed. In severe cases, infected ulcers may spread throughout the mouth and alimentary tract. His hair may fall from the head and body about 3 weeks after exposure.

The slightly injured recover quickly, but those who receive a heavier dose of radiation may continue gravely ill for weeks. The most severely injured may die within a few days or grow progressively worse over a period of weeks and finally succumb.

Phase IV

Patients who survive enter a convalescence during which weakness and fatigue are the outstanding symptoms. It may be months before the patients recover normal strength and weight. The skin hemorrhages disappear and the hair, if lost, gradually regrows. Usually within 6 months the patient feels completely well.

Protection

In general, there are two categories of protection against the effects of initial radiation. They may be summed up as distance and shielding. In other words, it is necessary either to get beyond the reach of the effects, or to provide protection against them within their area of damage. The first principle, that of distance, is utilized by the civil defense organization in its policy of the evacuation of populations from target areas, if time permits. However, this concept has been vastly complicated by the effect of fallout hazard extending far beyond the zone of direct damage. Yet, total evacuation could save a high proportion of the population from almost certain death if they remained in unprotected cities during a nuclear attack.

Shielding from an atomic blast is best provided by underground structures. A shelter must be designed to protect from blast, as well as radiation, and if located outside the area of heaviest damage shelters could save many people. As an example of the problem of providing adequate shelters, we know that most dwellings would receive considerable damage from a blast exerting a pressure of 2 p.s.i. Yet an adequate shelter in a target area should be able to withstand 30 p.s.i. maximum pressure. To provide protection from the radiation, the shelter should be covered with 6-1/2 feet of packed earth or 4-1/2 feet of concrete. It can be seen from this that buildings would very likely provide little protection from radiation and blast near the target center, and consequently evacuation remains our presently accepted policy.

Residual Radiation

Residual radiation, or "fallout," affects us much as initial radiation affects us. Here, however, we are not concerned with damage other than that brought about by contamination, because little or no actual physical damage results from this type of radiation. As a general rule, radiation from fallout will not bring about induced radioactivity, as results from the action of neutrons during initial radiation. However, any form of life will be affected by the ionizing radiations of fallout, because gamma rays, beta particles, and usually alpha particles will be present. These can and will cause the same symptoms of radiation sickness as that brought on by initial radiation. With large weapons, lethal amounts of fallout may be spread many miles by the winds.

In addition to the absence of neutron radiation in fallout, there are also other differences between residual and initial radiation. As a rule, the gamma radiations from fallout are less penetrating than those from initial radiation. Consequently, shielding need not be as heavy to provide the same safety factor as that needed for the higher energy gamma rays from a bomb blast. However, this is counterbalanced by some self-shielding when the radiation comes from one direction, as in a bomb explosion. By this we mean that one portion of the body may shield another portion from the full effect of the rays. However, in fallout the radiation comes from many directions and there is very little self-shielding of the body.

Beta Burns

Beta particle radiations are characteristics of fission products and can cause external injury to the body in two ways. If the fallout comes in actual contact with the skin and remains for any appreciable length of time, a form of radiation damage sometimes referred to as "beta burns" will result. In addition, in an area of heavy fallout, the whole surface of the body will be exposed to beta particles coming from many directions. Although clothing will afford considerable protection, the outer layers of the skin could receive a large dose of beta radiation and serious burns could result.

Fission products adhering to the hair of man or animals will also cause beta burns when heavy fallout is encountered. This often results in burns to the underlying

skin with accompanying temporary loss of hair. Burns associated with this type of radiation may not be apparent for 2 to 3 weeks and are slow healing.

Internal Sources of Radiation

Whenever fallout occurs there is a possibility that radioactive material will enter the body through the digestive tract (by the consumption of contaminated food or water), through the lungs (by inhalation of contaminated air), or through wounds or abrasions. The effects of nuclear radiations from internal sources are the same as from external sources, but even a very small quantity of radioactive material in the body can produce considerable injury.

In the first place, radiation exposure of various organs and tissues from internal sources is continuous, subject only to depletion of the quantity of active material in the body as a result of physical (radioactive decay) and biological (elimination) processes. Further, the body tissues in which injury may occur are nearer the source of radiation and not shielded from it by intervening materials. This is of particular importance with alpha and beta particles which cannot reach sensitive regions, except the outer layers of the skin, if originating outside the body. But if the sources, such as plutonium (alpha particle emitters) or fission products (beta particle emitters) are internal, the particles can dissipate their entire energy within a small, possibly sensitive, volume of body tissue, thus causing considerable damage.

Protection

The protection of personnel from fallout is much the same as it might be against the initial effects of an atomic bomb; that is, evacuation or shelter. However, due to the large area covered by fallout and the congestion involved in the evacuation of large cities, it may be preferable to consider the advisability of shelter from fallout.

Persons caught in fallout should take any cover available. The dust may descent from the atmosphere or be stirred by the wind, traffic movement, or other means. It should be kept off the skin and from entering the body. Persons caught in the open should cover their mouths with handkerchiefs and protect all parts of their bodies as far as possible. The dust should be brushed or washed off immediately. (See section on “Decontamination Stations”, page 143.)

Fallout shelters in outlying areas do not need the blast resistant construction of primary target areas; consequently, the cost of such construction would be considerably lessened. An adequate shelter for protection against fallout ideally would be underground and covered with 3 feet of packed earth or 2 feet of dense concrete and must have effective ventilation devices for bringing in filtered air and exhausting stale air. It should be equipped for occupancy for 2 to 7 days or longer, with supplies of food and water, and facilities for sanitation. Supplies, such as generators, monitoring devices, radios, and cots, are listed more fully in civil defense publications.

Inasmuch as the ideal is rarely obtainable, any building, particularly basements, can afford a measure of safety from fallout. A basement will provide protection against

90 percent of the harmful rays from fallout and a one-story brick building will attenuate the rays by 85 percent. It is important here to remember that during the early stages of fallout, the activity of the fission products is very high, but by the end of 49 hours, or roughly 2 days, it will have decreased to about 1 percent of the value at 1 hour after the explosion.

It is difficult to indicate in advance at what value of the external dose rate it may be possible to leave the shelter. It would depend in large measure on how long it would take to evacuate the area or to decontaminate the premises, as well as upon the total dose received during the shelter period. Answers to these questions can be adequately furnished only by personnel trained in monitoring and dose rate calculation work. As a rule, however, after a few days it will be safe to evacuate the shelter by a route which will involve a minimum of radiation exposure.

Basic Principles of Radiation Protection

Certain principles for protection of personnel from all types of radiation are recognized, regardless of the type (particle or ray), source, or energy of the radiation. The application will vary to some extent, depending on the type and energy of the source. Broadly speaking, these principles should be observed whether in dealing with a nuclear explosion, a reactor accident, or industrial use of radioactive materials.

External Radiation Hazards

X-rays and gamma rays are the most common type of radiation hazard. Both are usually capable of deep penetration into the body and, as a result, no organ is beyond the range of their damaging powers. The most common source of X-rays is, of course, the X-ray machine. Gamma rays are emitted from nuclear reactors, particle accelerators, and radioactive isotopes found in fallout and radioactive sources used in training, research, and industry.

Beta particles may or may not constitute an external hazard, depending on their energy and intensity. Beta particles with enough energy to penetrate to the basal layer of the epidermis are considered external hazards. Radioactive isotopes in fallout and source material, as well as high-energy particle accelerators, may be sources of beta radiation.

Neutrons, because of their high-penetrating powers, are considered external radiation hazards. They are produced by high-energy particle accelerators and nuclear reactors (a nuclear weapon is also a type of nuclear reactor) in abundant quantities. Neutrons are perhaps the most dangerous of all external radiation because they have so far proved to be the most difficult to monitor, and they have a large potential for causing tissue damage.

Control of External Radiation Hazards

Monitoring is the first requirement of hazard control so that the degree of hazard is known. Only after finding out the intensity and type of radiation present can intelligent protective measures be taken. Monitoring should include area survey with low

intensity Geiger-Mueller or scintillation meters and/or the higher intensity monitoring devices, such as ion chamber meters. Too, personnel monitoring with the use of one or more dosimeters is very important in order to know the total dose of radiation received by personnel.

Distance is not only very effective but also in many instances the most easily applied principle of radiation protection. When gamma or X-radiation is confined to a point source (that is, one small area), distance will afford protection in a degree that can be accurately calculated by what is known as the "inverse square law." The inverse square law states that radiation intensity from a point source varies inversely as the square of the distance from the source. This is expressed mathematically as:

$$\frac{(\text{Intensity}_1)}{(\text{Intensity}_2)} = \frac{(\text{Distance}_2)^2}{(\text{Distance}_1)^2}$$

This equation shows that doubling the distance from the source decreases intensity by a factor of 4; increasing the distance by a factor of 3 reduces the radiation intensity by one-ninth of its value, and so forth.

Shielding is one of the most important principles of radiation protection. However, in considering shielding we should keep in mind:

1. That persons outside the "shadow" cast by the shield are not necessarily protected.

2. That a wall or partition is not necessarily a safe shield for persons on the other side.

3. That, in effect, radiation can "bounce around corners," i.e., it can be scattered.

In shielding from gamma or X-radiation, it is well to recall that these rays can penetrate to great depths. For example, the intensity of gamma radiation at an average energy of one million electron volts is decreased by only one-half in passing through 1/8 inch of lead. The protection afforded by clothing is almost negligible. Over 300 layers of wool or cotton would be required to reduce the intensity by one-half. The most effective materials for gamma shields are made up of those elements having high atomic numbers and high densities. Such elements are uranium, thorium, lead, gold, and tungsten. The weight and cost of these metals limit their use in shielding; therefore, less costly medium-weight metals such as iron, aluminum, nickel, and chromium are used.

Beta particles are also attenuated by shielding and relatively little is necessary to absorb them completely. Therefore, the general practice is to use enough shielding for complete absorption. For low energy beta emitters in solution, the glass container generally gives complete absorption. In many cases plastic shielding is effective and convenient.

Fast neutrons are poorly absorbed by most materials; therefore, it is necessary to slow them down for efficient absorption. Since the greatest transfer of energy takes place in collisions between particles of equal mass, hydrogenous materials are most effective for slowing down fast neutrons. Water, paraffin, and concrete are all rich in hydrogen and, thus, important in neutron shielding. Once the neutrons have been reduced in energy, they may be absorbed by boron or cadmium.

Exposure time is the fourth factor in personnel protection from external radiation hazards. On occasions it may be necessary to exceed the maximum permissible dose in order to get a job done. This can be done with safety by limiting the total exposure time so that the average maximum permissible value for a day based on the maximum permissible dose of 0.1rem per week is not exceeded. It may sometimes be necessary to work men in relays in the same job so that the tolerance dose is not exceeded by any one man.

As a rule of thumb in determining the approximate decay of fission products shortly after a nuclear detonation, the 7-10 rule is used. This means that for every sevenfold increase in time from the bomb burst, the intensity of radiation will be decreased by a factor of ten. From this we can see that 7 hours after the explosion, the radiation is one-tenth of the intensity after 1 hour. As an example, if the intensity is 500 r/hr 3 hours after the detonation, the intensity will be near 50 r/hr 21 hours after the burst.

Internal Radiation Hazards

Methods of exposure to internal radiation hazards are by ingestion, inhalation of air containing radioactive materials, by absorbing a solution of radioactive materials through the skin, and by absorbing radioactive material into the bloodstream through a cut or break in the skin. The danger of ingesting radioactive material is not necessarily that of a large amount swallowed at one time, but rather the accumulation of small amounts on the hands, cigarettes, or foodstuffs, and other objects, and thus bringing the material into the mouth.

Sources of internal radiation hazards have a strong bearing on the hazard to the individual, because of differences in type of radiation emitted, the energy, the physical and biological half-life of the material, and the radiosensitivity of the organ where the isotope localizes. Alpha and beta emitters are the most dangerous radioisotopes from an internal hazard point of view because their specific ionization is high. Isotopes with half-lives of intermediate length are the most dangerous because they combine fairly high activity with life sufficiently long to cause considerable damage. Polonium is an example of a potentially serious internal hazard. It emits a highly ionizing alpha particle of energy 5.3 Mev, has a half-life of 138 days, and “creeps” out of containers.

Control of Internal Radiation Hazards

The use of protective devices and the employment of good handling techniques are instrumental in the control of internal hazards. Dust should be kept to a minimum by the elimination of dry sweeping and the use of air filters. Laboratory operations

with radioactive materials should be carried out in hoods so designed that room air contamination is kept at a minimum. The exhaust air must be filtered, and, if necessary, washed to eliminate any possible public hazard. Protective clothing should be worn so that permanent clothing does not become contaminated. This helps to eliminate the spread of contamination. To prevent the inhalation of radioactive materials, respirators should be available in emergency operations in areas where the concentration of air-borne activity is above maximum permissible levels. Eating and smoking in areas of fallout or where radioactive materials are handled should be prohibited to reduce the ingestion hazard. Laboratories and power reactor stations should be so designed and constructed that contamination can be readily accomplished, if necessary. Also, proper instruments should always be used in handling radioisotopes in order to reduce the probability of accidents.

Waste Disposal

An important feature of personnel protection, from a public health standpoint, is the control of radioactive waste material from nuclear power plants and laboratories. The danger associated with radioactive wastes is mainly due to the possibility that the soil or water may become contaminated, with the result that active material may ultimately find its way into food or drink consumed by human beings. To prevent this undesirable contamination of a food or water supply, means have been developed to eliminate the hazard of radioactive waste material by dilution, concentration, or confinement, or often by a combination of two or three of these methods.

In the disposal of gaseous wastes, as those resulting from aircooled reactors and from the treatment of fission products, the air is passed through precipitators and filters to remove suspended particles, and then is discharged through a tall stack. By exhasuting through a tall stack, the small amounts of radioactive material are mixed with large quantities of atmospheric air, and the activity is greatly diluted. In order to make sure there is no contamination, the air in the vicinity of the reactor building, and at distances up to several miles from the stack, should be continuously monitored for radioactivity.

In disposing of liquid effluents, as in the case of water from a water-cooled reactor, the contaminated water is usually stored for a time to allow radioactive decay to occur, and then discharged into a river at a controlled rate.

Because of this careful control, the river water, after the usual filtration treatment, has proved completely satisfactory for domestic use. Liquids having a higher concentration of radioactive products are held for a longer period of time and then extensively diluted and dispersed in large volumes of water. Or liquid wastes of certain types may be run directly into pits dug in the ground where the radioactive material is retained by the soil, and the residual liquid seeps away. Highly contaminated liquids usually must be concentrated by evaporation of the excess moisture or by concentration in a special clay. The concentrated waste is either stored in underground tanks or it is buried directly in the ground at a suitable location.

Solid wastes, as a rule, are small in amount and are buried in the ground in a protected area. Burning is not satisfactory for disposal unless special incinerators are used which do not permit the radioactive smoke particles to escape.

Permissible Levels of Exposure

External Radiation

In view of the harmful nature of radiations from radioactive substances, particle accelerators, and nuclear reactors, and the lack of any established method of treating the resulting injuries, the obvious procedure is to take all precautions go avoid over-exposure. The term "over-exposure" is used here because we have reason to believe that the body, with the exception of the reproductive organs, will recover from small doses of radiation by the replacement of damaged or killed cells by new cells. Normally, each of us receives about 0.14 to 0.16 r per year due to natural radiations from body constituents, cosmic rays, and emanations from radium, etc., in the earth. So we have ample evidence to show that restricted exposure to radiation is not serious. (See section on "Effective Residual Dose," page 114.)

In determining the limit below which there will be no consequences, many factors have been considered, and the recommended limit of exposure is set at the present time as 0.1 rem per week total body radiation. As we know, small areas can be exposed to very much larger quantities without serious injury, but here we are referring to the dose that can safely be absorbed over the whole body within 1 week. Consequently, care must be taken that the whole body is never exposed to a high radiation intensity, even for a short period of time.

In the event of exposure to two or more kinds of radiation, the equivalent of the total absorption must not exceed 0.1 rem per week or 3 rems per 13 consecutive weeks. The National Committee on Radiation Protection recommends that the total accumulated dose should not exceed an average of 5 rems per year past the age of 18 years. For the general population, it has been suggested that the total exposure, from all sources of radiation, including the natural background, should not exceed an average of 14 rems per individual from conception to the age of 30 years, and one-third that amount in each decade thereafter.

Internal Radiation

Our function here is to place limits upon the rate of entrance of the various radioactive materials into the body and to establish maximum permissible concentrations for them.

The maximum permissible body burdens of many radioisotopes have been established, e.g., for radium 226 (0.1 microcurie) and iodine 131 (0.3 microcurie). For most radio elements which, like radium, accumulate in the skeleton, maximum permissible amounts have been estimated. Thus, for plutonium 239 the limit has been set

at 0.04 microcurie for soluble compounds and 0.008 for insoluble sources, the former having a greater tendency to be eliminated. The maximum permissible body content of strontium 90 for occupational exposure is 2 microcuries. For radioisotopes which do not concentrate in bone, it is assumed the body content should not exceed the lowest levels which will result in an average dose in some part of the body, other than the reproductive organs, of 0.1 rem per week. (See section on "Exposure Criteria and Denial Time," page 103, for further elaboration of this subject.)

Emergency Levels of Exposure

During emergency conditions, the hazards involved must be closely weighed against the need for access to certain areas, or a shortage of food and water. Consequently, emergency levels have been determined which responsible officials can use as a guide. However, it must be emphasized that these are not normal permissible levels and should be considered only in event of an emergency.

In the establishment of these levels of permissible emergency exposure, it is suggested that the reader refer to the chapter entitled "Exposure Criteria and Denial Time," especially to the section entitled "Allowable Emergency Exposures to Radiation," page 104.

As with any hazard, the cardinal principle must be: <u>Avoid all unnecessary exposure</u>. Training activities should involve no more than the maximum permissible exposure of 0.1 rem per week; most of them can, and should, be at exposures far less than this.

In <u>emergency</u> operations where appreciable amounts of radiation are present, one should not hesitate to accept an exposure to the whole body of 25 roentgens in a single day.

The suggested <u>emergency levels for food and water</u> immediately following a nuclear explosion are based on a 10-day consumption period and a 30-day consumption period.

Time		Beta or Gamma Emitters	Alpha Emitters
10 days	Water	9×10^{-2} µc/cc.	5×10^{-3} µc/cc.
	Food	9×10^{-2} µc/gm.	5×10^{-3} µc/gm.
30 days	Water	3×10^{-2} µc/cc.	1.7×10^{-3} µc/cc.
	Food	3×10^{-2} µc/gm.	1.7×10^{-3} µc/gm.

Basic Radiation Protection Rules

1. Wear personnel metering equipment (dosimeters) at all times.
2. Wear protective clothing and equipment when working in contaminated area or with contaminated material.

3. Monitor any radioactive material before removing from a contaminated area.

4. Monitor personnel following exit from any contaminated area.

5. Do not eat or store food or beverages in a contaminated area.

6. Do not smoke in contaminated areas.

Questions

1. The most far ranging immediate hazard from a nuclear detonation is from:

   a. blast,
   b. heat,
   c. initial ionizing radiation, or
   d. residual ionizing radiation.

2. According to the inverse square law when the distance from a point source is tripled, the intensity is reduced by a factor of:

   a. one-third,
   b. one-half,
   c. three, or
   d. nine.

3. The disposal of radioactive gaseous wastes is usually accomplished by:

   a. confining the gas in a pressure tank,
   b. exhaust to the air through a tall stack,
   c. exhaust to the air following precipitation and filtering, or
   d. dilution with large amounts of air before exhausting into the atmosphere.

4. An adequate shelter for protection against fallout should be underground and covered with packed earth to a depth of:

   a. 3 feet,
   b. 6 feet,
   c. 1-1/2 feet, or
   d. 10 feet.

5. Which of the following tissues is considered as the most sensitive to radiation damage?

   a. skin,
   b. lymphoid,
   c. nerve, or
   d. bone.

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SALVAGE AND DECONTAMINATION[1/]

In the event of total war waged with nuclear weapons, the death, destruction, and chaos would be on a scale unknown to the modern world. In addition to those killed by the initial effects of the blast, untold thousands would be made homeless and additional thousands would be injured and in need of medical attention, unable to care adequately for themselves. Within a short time radiation sickness would appear and disable many more persons, who on first appearance were not seriously affected by the blast. The public utilities of entire cities would be disrupted with the resultant failure of electrical and telephone service and the breakdown of water distribution and sewage disposal facilities. Those of the population fortunate enough to survive the attack and escape the disabling or lethal path of heavy fallout would have the enormous task of providing medical attention, shelter, and food for the hordes of evacuees from the devasted areas.

Under such conditions rioting and looting might break out, especially in the case of widespread famine when the normal supply of food is halted. To meet these possibilities, martial law and rigid police enforcement of the distribution of existing food

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1/ Prepared by Robert A. Moody, Meat Inspection Division, Agricultural Research Service, U. S. Department of Agriculture.

and drug supplies would be necessary to insure the best distribution, stop hoarding, and prevent consumption of grossly contaminated foods. Such an embargo would prevent release of any food supplies for consumption without the written permission of an authorized person after the safety for use of the food had been established.

Where to Begin

Total destruction will be complete in an area around ground zero. Surrounding this will be a larger area of severe destruction with wrecked buildings, fire damage, and possible heavy radioactive contamination. Beyond the area of severe damage will be other areas of lesser damage with broken windows and, in places, radioactive contamination. The work of salvage must begin in these areas of slight damage. The reason for this is twofold: Meat and other food supplies will be more readily salvaged from these areas, and later entry into the more heavily damaged areas will give additional time for the radioactivity of these areas to "cool off" through radioactive decay. This will also serve to decrease the danger from prolonged exposure of salvage workers in the area of heavier contamination. Civil defense officials plan, in event of attack, to map areas according to the radiation levels found. In order to avoid dangerous exposure of the personnel, salvage workers must consult such maps before they enter contaminated areas.

Salvage

The principle of salvage of damaged or contaminated food is to segregate the contaminated from the uncontaminated and to clean up the former, if possible. Often the activity or damage will be found only on the surface of a stockpile and by careful removal of the surface, product or cans will be uncovered which have suffered no damage or contamination. Such unaffected product could be released for immediate consumption. In the portion that must be decontaminated before use, trimming or the dusting or washing of containers with a detergent solution probably will remove much of the contamination. Where the contaminating material is radioactive fallout, the contents of sealed, undamaged packages or containers will not be contaminated.

Refrigerated Products

With the breakdown of refrigeration, which is very likely in a damaged area, perishable products may not be possible to salvage. If bacterial damage is not too great, they may be washed or trimmed and cooked thoroughly before eating.

Boxed and Canned Products

Products or containers would very possibly be contaminated by nonpotable water in the event of fire fighting or sewage problems. If perishable product were so con-

taminated, vitally needed supplies could be partially salvaged by trimming and thorough cooking before consumption. Boxed products might be similarly handled to provide an emergency supply of meat, and canned goods may be sterilized by washing, dipping in a chlorine solution, and drying. Canned goods must be carefully examined for rust spots and damaged stocks used promptly following washing. The monitor's knowledge of the normal appearance of cans will enable him to determine the soundness of the product involved. Damaged cans should be held for a 10-day incubation period, if possible, after disposal of the obviously ruptured cans. The absence of proper incubation temperatures may require longer holding if emergency conditions permit.

Products in Glass

Glass containers will be especially subject to crushing and there is also the possibility of a ruptured seal between the lid and container from pressure surges. Radioactive material or contamination from polluted water easily lodges under the screw caps or friction type lids and is difficult to remove. In event the contamination is from water only, the contents may be salvaged by sterilization before using.

Meat Food Product Ingredients

Meat food product ingredients, such as cereal, will cake when moistened and some undamaged material may be recovered from the inside of bags or drums. Fresh vegetables, as potatoes, carrots, and onions, if not crushed, can usually be salvaged by peeling or thorough scrubbing.

Trimming

Unlined cloth or porous paper over a product will not always protect it from radioactive fallout so, in event careful monitoring indicates contamination is present, the product should be trimmed or portions next to containers discarded. Naturally, such trimming or discarding should be done in a manner that will not contaminate the rest of the product.

Glass Splinters

The British found in World War II that one of the most troublesome results of bombing was the contamination of products with glass particles from shattered windows, broken glasses, etc. The splinters were driven into cans and through other types of product. No really satisfactory salvage procedure was ever developed for this type of contamination.

Practical Handling

A practical procedure to follow in the recovery of foodstuffs from a contaminated area is to plan for a minimum stay in the contaminated area consistent with recovery

of the product. After recovery, decontamination procedures can in many cases be accomplished in areas where there is less danger of personnel exposure. In World War II, the work of inspecting stocks of canned goods in which spoilage was occurring was more efficiently performed by small teams composed of two trained personnel and three or four laborers. The operation consisted of inspecting while the opened cases moved along a roller-type conveyor system.

Induced Radiation

Generally speaking, induced radiation of foodstuffs would not be a problem in event of nuclear warfare. The heat and blast in the area of induced radiation would in all likelihood destroy the food to the extent that slavage would be impossible. However, in event that meat supplies near the blast center did survive, knowledge of the effects of the neutron flux on the product would be important in deciding the acceptability of the food for emergency use. We know that the bones of critically exposed meat will have a higher concentration of activity than the meat itself and should be discarded. Salt and curing mixtures will have relatively high readings, but the activity will rapidly decay. High phosphorus (nonfat dry milk) and high salt (cured and processed meats) content foods will show higher readings than other foods when exposed to the neutron flux. Phosphates, as those used in curing mixtures, will readily be made radioactive by neutrons and the activity will decay more slowly than the activity due to sodium content. Nonfat dry milk develops a distinct off flavor when induced radiation is present. This is apparent on being reconstituted.

Scavengers

The disruptions brought on by conditions making salvage of meats necessary also favor increased rat and other vermin populations. Special attention must be given to vermin eradication and the prevention of their access to food since their contamination and disease spreading threat is a more serious one to the community during disaster conditions. Too, during wartime conditions with the bombing of cities, domesticated dogs and cats are often abandoned to fight and forage for themselves. Such animals often band together and travel in packs to create a nuisance as well as a danger to people and food stocks.

Animal Salvage

Animals exposed to radiation would quite likely be presented for slaughter in event of a nuclear catastrophy so that a continuing supply of meat may be supplied to the public and with the attempt to obtain salvage value from the affected animals. In considering the disposition of such exposed animals, several factors must be considered. If the hair and hide are contaminated with fallout, the animal should be decontaminated by washing prior to slaughter. It may be that the hide, even though washed before slaughter, cannot be salvaged because of the radioactivity remaining. In like manner, fallout ingested by livestock may become a hazard to the consuming public if large amounts of the radioactive material are found in the digestive tract. If such should occur, it might be advisable to condemn the digestive tract, yet salvage the meat from

the carcass. Other organs particularly susceptible to contamination would be the lungs, because of inhalation of radioactive material, the liver, lymph nodes, kidneys, thyroid glands, and bone. Fortunately, muscle tissue is one of the tissues least apt to contain radioactive substances which might be ingested.

Animals exposed primarily to external radiation present another phase of the problem. Here, ingestion of fallout is probably of little or no consequence but the animals may have been exposed to a strong radiation field and symptoms of radiation sickness may be evident. In such cases it would normally be safe to pass the animals for food if no ante- or post-mortem changes were present. This is based on the premise that irradiation of animals is harmless to the consumer unless pathologic changes resulting from the radiation become evident. Even though it were known that the animals were exposed to a lethal dose of radiation, it would be advisable to pass such animals for food under emergency conditions if no pathology were evident at the time of inspection. Also, it would be considered safe to utilize the meat of animals showing symptoms of radiation sickness if the animals were held until such time as they are completely recovered before slaughtering.

Decontamination

In a nation subjected to nuclear attack, the area made useless by massive amounts of fallout exceeds many times the area of destruction caused by the blast. With the widespread distribution of the meatpacking industry, it is only natural that many plants would be only slightly damaged or be entirely undamaged, yet it would not be possible to operate the plants safely because of contamination with fallout. These are the plants that could be made operative through the effective use of decontamination procedures, if the general contamination of the entire area is at a low enough level to allow entry by salvage and decontamination workers. Consequently, plants in this category will be the ones we have in mind when discussing decontamination procedures.

The problem is to render the area or plant safe for personnel to establish once again a production schedule and be able to handle meats and products in a manner that will assure freedom from contamination. It may be that total decontamination is impossible, but at least the radiation can be reduced to relatively safe levels under emergency conditions. However, even under emergency conditions, the meat processing must not add to the radioactive burden. It follows that with all the problems of a major disaster, including unprecendented mass evacuation, meat inspection personnel will be better able to achieve satisfactory plant operational conditions if they know how decontamination is accomplished.

It is not contemplated that plants in heavily contaminated areas will attempt immediate production of meats for human consumption but will try only to move into trade channel those foods capable of salvage and certain decontamination steps may be necessary before these salvage efforts are made. Contamination will follow the fallout pattern and as fallout cannot be neutralized nor its natural rate of decay hastened, decontamination is necessary if the use of plant facilities cannot await natural radioactive decay.

Fallout is initially a surface contamination; however, the forces of nature do provide a continual redistribution of significant amounts of the fallout. Air currents will provide a continuing redisposition of radioactive dust for days and meats must be guarded against dust contamination and the need for supplemental decontamination. Rains carry fallout deeper into the ground and heavy rains wash this material into water reservoirs but fortunately the water problem is not so severe as one might expect.

Initially monitoring will suffice to determine if decontamination has been effectively accomplished. Fallout activity readings will be at first largely due to gamma and beta emitters. Alpha particles from unfissioned bomb components may be present but will be intimately mixed with beta and gamma emitters. It is possible that special monitoring may be necessary to detect alpha contamination after the beta and gamma emitters have decayed.

Many methods of decontamination are available and needs of the site to be decontaminated, availability of materials, and disposal of the wastes are of prime consideration in selecting the method one will use. Thorough planning is necessary before decontamination is attempted. Highly contaminated areas might better be left for decay to occur while decontamination of less dangerous areas is proceeding. In areas where the time for personnel exposure is important, dry runs of the procedure to be employed are suggested. Rotation of personnel and the use of protective clothing are two methods of limiting exposure.

Methods of Decontamination

Gross Removal

Bulldozing, shoveling, and sweeping are methods used in handling gross contamination. Here the contaminating material must be disposed of in an isolated area, dumped in a pit, or similarly handled. Personnel must be adequately protected from dust. Dust should not be created that will spread contamination to noncontaminated areas or areas already cleaned. Walkways will give considerable personnel protection and may be formed on the outer premise of the plants by shoveling or bulldozing the surface layer to one side.

Vacuum Cleaning

This is the most desirable method of removing radioactive dust. Vacuum cleaners must be equipped with a water vapor dust trap or auxiliary exhaust filters to trap the radioactive wastes for easy disposal. Supplementing this method with moist wiping, steam cleaning, washing, etc., often will be necessary. Removing radioactive dust before washing surfaces, such as concrete, that tend to absorb water and carry activity into its deeper layers is also important.

Hosing Down

This method of cleaning probably would be the most frequently employed. Fire fighting equipment may offer a valuable supplement to plant facilities by the use of

their specialized nozzles and pressure systems; however, a water shortage following attack may preclude this method as the main source of decontamination. Roughly, the use of 250 gallons of water per minute applied to a surface area of 4 square feet may reduce activity 50 percent. Obviously the disposal of these large amounts of water wastes may be a problem and special drainage facilities should be prepared, if possible. A Geiger check of the activity level as work progresses will enable intelligent modification of the decontamination procedure. Work from the windward side and stand 15-20 feet away to avoid the spray. Follow the normal procedure of working from the high to the low areas of contamination.

Steam Cleaning

Steam cleaning may reduce the activity by as much as 90 percent. By rule of thumb, 150-200 pounds' pressure will clean 4 square feet per minute if the stream gun is held about 2 feet from the surface. High-pressure hot water jets are also good and here again the operator should stand 15-20 feet from the area being cleaned.

Scrubbing

Scrubbing, manual or mechanical, may be particularly useful in supplementing areas that have not been satisfactorily cleaned by other methods. Brushes, rags, or brooms can be used for this purpose and the use of detergents will reduce the amount of scrubbing necessary.

Detergents

Detergents of the soap and soapless types will have an important part in packinghouse decontamination, especially where the surface is oily or greasy. The soapless detergents are effective in either basic or acid solutions; however, detergents are not effective where the contamination has penetrated the surface.

Complexing Agents

Complexing agents, such as citrates, oxalates, and carbonates, form chemical combinations which are readily removed. It is recommended that a hot 3-percent solution be applied and the surface kept wet with the complexing agent for a 30-minute period. Complete flushing with water after the complexing action may reduce the activity by 90 percent. Complexing agents have little penetrating power and oxalates are not normally approved for general cleaning in establishments operating under Federal meat inspection.

Strong Caustics

Strong caustics are used in decontamination procedures chiefly to remove contaminated paint surfaces. Four pounds of lye added to 10 gallons of water will remove

400 square feet of paint, and 6 pounds of boiler compound added to this solution will increase the effectiveness. To thicken this solution so that it will stay on walls, 3/4 of a pound of corn starch may be added. A dipping process may be used for some objects, allowing them to soak from 15 minutes to 2 hours. The use of long-handled mops to apply the solution and scrappers to remove the paint will add to the protection of personnel during the operation. Trisodium phosphate may be substituted for lye.

Organic Solvents

These solvents consist of kerosene, gasoline, alcohol, ether, turpentine, carbon tetrachloride, and commercial paint removers. Limited use for these agents is contemplated in decontamination. The dipping of small hard to clean objects or wiping greasy motor frames are examples of possible uses of these solvents.

Strong Inorganic Acids

Strong inorganic acids, particularly sulfuric and hydrochloric acids, are useful to clean contaminated pipe systems and will readily remove contamination from rusty metal surfaces when combined with certain organic acids. Use 13 gallons of concentrated hydrochloric acid in 100 gallons of solution for pipe systems. Circulate 2 to 4 hours, flush with plain water, a water detergent solution, and then finish the flushing with another plain water rinse. Only competent personnel should attempt to use strong inorganic acids. To remove rust coating from metals, 2 ounces of sodium oxalate, sodium citrate, or sodium acetate in 1 gallon of 1:10 acid solution is suitable. This solution will usually reduce the contamination on metals by 90 percent. A badly weathered surface may require a second application.

Vacuum Blasting

The large areas of concrete surfaces may call for wide use of this method of decontamination. Vaccum blasting is the most efficient technique of abrasive decontamination. Fine particles of steel grit are shot by air pressure against the contaminated surface as the head, which consists of the jet with surrounding jacket, is moved over it. The vacuum jacket surrounding the jet draws the grit and loosened particles of the surface into a chamber where the grit is separated and reused. The contamination is trapped, under control, and ready for disposal. Large surfaces, both porous and nonporous, can be decontaminated by vacuum blasting. The procedure is rapid, simple, and safe. Progress can be checked by a survey instrument.

Sand Blasting

Sand blasting satisfactorily erodes a surface but tends to spread the contamination. Dust and sand can later be removed by vacuum cleaning or washing. Sand blasting with wet sand is not feasible for porous surfaces since the water carries loosened activity into the deeper layers of the material.

Flame Cleaning

Flame cleaning is reputed to trap radioactive substances on wood and concrete by burning before they can sink deeper into the material. Then they can be removed by abrasion. Awaiting for natural radioactive decay to occur might be preferable to the use of this slow and expensive method.

Sealing

Examples of sealing are resurfacing with concrete, asphalt, or paint. This effectively removes the hazard of beta and alpha contamination. Paints or plastics might be used on certain pieces of equipment or building surfaces. Cleaning the surface before sealing is desirable.

In utilizing any of the above methods of decontamination, ample ventilation must always be supplied. This is especially true where the cleaning will result in dust or mist in the area. If such ventilation is not possible, gas masks may provide effective protection against inhalation or ingestion and protective clothes against body contamination. Also, the contaminated or clean areas should be posted with signs, if feasible. This is particularly important where large numbers of people are working in the area.

Workers in contaminated areas should wear coveralls (with as few openings as possible), boots, gloves, cap, and protective mask. The clothing should be tightly buttoned at the neck and tied at the wrists and ankles. Two-inch masking tape provides rapid and effective closure of protective clothing openings. Cloth booties over shoes when working in dry areas or rubber boots in lieu of shoes for wet operations should be used. Water hosing and steam cleaning operations call for waterproof outfits, including googles and masks. Rubber gloves should be worn in wiping and brushing procedures. Completely impermeable suits are called for in vat dipping operations. Sand blasting operators should wear both a hood and a mask.

Decontamination Stations

Where large-scale salvage and decontamination work is necessary in a contaminated area, normally it would be advisable to set up stations near the operations where the workers could be monitored, decontaminated, and their clothes and equipment properly handled. Here, the workers from a contaminated area remove their clothing and enter the showers. After a scrub down, they would be closely monitored, giving special attention to the hair and fingernails. Verseene base ointment, light scrubs, and sweating procedures, when necessary, supplement showering. If decontamination has been successful, workers dress in clean clothing and leave the station for noncontaminated areas.

Contaminated clothing can be salvaged to a large degree, but special laundering techniques are usually employed and the clothing should not go to a commercial laundry unless special arrangements have been made. An effective procedure to follow in decontaminating clothing is to separate the clothing into different activity levels. Three washes in hot detergent (not soap) are followed with three washes in warm 1-percent versene detergent. Thorough rinsing is followed by drying. Each article is

monitored and before release must measure less than 7 mr/hr. on garment contact. Garments exceeding this activity may be held for radioactive decay. Rubber and plastic materials are readily decontaminated in a warm detergent wash.

Water Decontamination

The problem of water decontamination will often be one of the municipality that furnishes water to the plant involved. Here the process ordinarily used in the purification of the city water supply may suffice to reduce activity to acceptable levels. If the contamination is heavy, additional techniques may be required in order to provide potable water. Such purification methods as ion exchange, excess lime-soda softening, phosphate coagulation, and the use of high specific surface absorbents as metallic dusts, clays, and activated carbon would be used only by experts. Reevaluation of plant facilities may have to be made, too, when water enters the potable supply after flowing over condensers or after having been stored in tanks or reservoirs on the plant premise. Contaminated wells might again be usable after providing an effective seal against further contamination and pumping for several hours. Often the natural processes that occur with the flow of water through the absorbent earth layers effectively remove radioactive contamination. Again, if time permits, a contaminated water source can be bypassed while radioactive decay reduces the activity to a safe level.

Questions

1. As a rule, salvage operations following a nuclear detonation should begin in the areas of:

   a. total destruction,
   b. heavy destruction,
   c. moderate destruction, or
   d. light destruction.

2. Undamaged canned products, moderately contaminated with fallout, should be:

   a. destroyed,
   b. washed and monitored before opening,
   c. set aside for decay of fallout to occur, or
   d. immediately opened and contents monitored.

3. Apparently healthy animals from a fallout contaminated area are presented for slaughter during time of emergency. Which one of the following organs could be eaten with the least hazard?

   a. muscle,
   b. liver,
   c. kidney, or
   d. paunch (tripe).

4. Animals presented for slaughter showing symptoms of radiation sickness would be handled as follows under emergency conditions:

   a. slaughtered for food,
   b. destroyed for food purposes,
   c. held until recovered before slaughter, or
   d. slaughtered and the parts monitored for hazard.

5. The most effective method of removing radioactive dust from a smooth surface is by means of:

   a. hosing down,
   b. scrubbing,.
   c. steam cleaning, or
   d. vacuum cleaning.

References

(1) Basic Radiological Safety Training Manual. Reynolds Electrical & Engineering Co., Inc., Health and Safety Department, Radiological Safety Division, February 1957.

(2) Civil Defense Information for Food and Drug Officials, 2nd Edition. Food and Drug Administration, U.S. Department of Health, Education and Welfare, December 1956.

(3) Radiological Health Training Syllabus. Robert A. Taft Sanitary Engineering Center, U.S. Department of Health, Education and Welfare, 1956.

FALLOUT ON SOILS, WATER, AND PLANTS (DEPOSITION AND MIGRATION)[1/]

Composition of Fallout

The composition and size of particles formed in nuclear detonations are determined in the first few minutes. The composition of fallout depends upon two factors:

1. The kind of material that gets into the fireball. (This includes soil, rock, water, etc., plus whatever materials make up the bomb case and supporting structures.)

2. The rate of cooling of the fireball.

1/ Prepared by Walter R. Heald, Soil and Water Conservation Research Division, Agricultural Research Service, U. S. Department of Agriculture.

The fireballs and clouds formed by the kiloton types of bomb explosions in Nevada were composed largely of silicates from the surrounding soil and rocks or of magnetite which came from the iron of the towers. The total heat capacity of tower debris is small resulting in rather slow cooling for bursts of this size. Strontium 90 is formed by the decay chain Krypton-90 (Kr^{90})$\longrightarrow$Rubidium 90 (Rb^{90})$\longrightarrow$Strontium 90 (Sr^{90}). The noble gas, Krypton-90 is not incorporated into the matrix, but Rubidium 90 may be if the matrix is still molten when sufficient Rb^{90} has formed. If the matrix remained molten 2 minutes, about 95 percent of this decay series would be incorporated as the debris cools. That is, Rb^{90} and Sr^{90} are absorbed by the molten particles and diffuse through the particles—resulting in most of the Sr^{90} being trapped on the inside.

On the other hand, the fireballs of megaton surface bursts in the Pacific were cooled relatively rapidly due to the extremely large amounts of water and coral rock which were incorporated into the fireball. The matrix consisted primarily of $CaCO_3$, CaO, and NaCl plus whatever metals and materials were used to form the bomb. This matrix was relatively soluble, completely acid-soluble. Thus, the composition of the bomb, type of detonation, and surrounding material determine the biological availability of the Sr^{90} in the fallout.

Kiloton nuclear detonations result in what is termed "local fallout" and trophospheric fallout since most of the debris is not carried high enough to enter the stratosphere. The particles tend to be large because the fireball stays hot for a rather long period. All this results in rapid settling of the debris. Megaton detonations blow much debris into the stratosphere which is eventually deposited as world-wide fallout. This material is of a relatively fine particle size.

It has been estimated that when a fireball from a kiloton detonation touches siliceous soil up to 50 percent of the Sr^{90} may be biologically unavailable. World-wide fallout is mostly soluble carbonates, chloride, etc., and is probably nearly all biologically available.

Distribution of Fallout

The residence time of bomb debris in the atmosphere is determined not only by its placement in the stratosphere or troposphere, but also by the latitude and the time of year it is injected into the atmosphere. It has been found that debris put into the arctic stratosphere in the autumn falls out more rapidly than that injected at any other time or place. Deposition in the middle latitudes appears to result from a stratosphere "half-residence time" of one-half to one year, compared with one to five years "half-residence time" over lower latitudes. After debris gets into the troposphere its "half-residence time" is about one month. All these facts make it evident that the region between 30° and 45° north latitude gets a high percentage of the debris put into the atmosphere. This is illustrated in Figure 39.

The preceding information was largely gleaned from soil, air, and water samples. One fact that clearly stands out is that the amount of world-wide fallout is related to rainfall as shown on page 148.

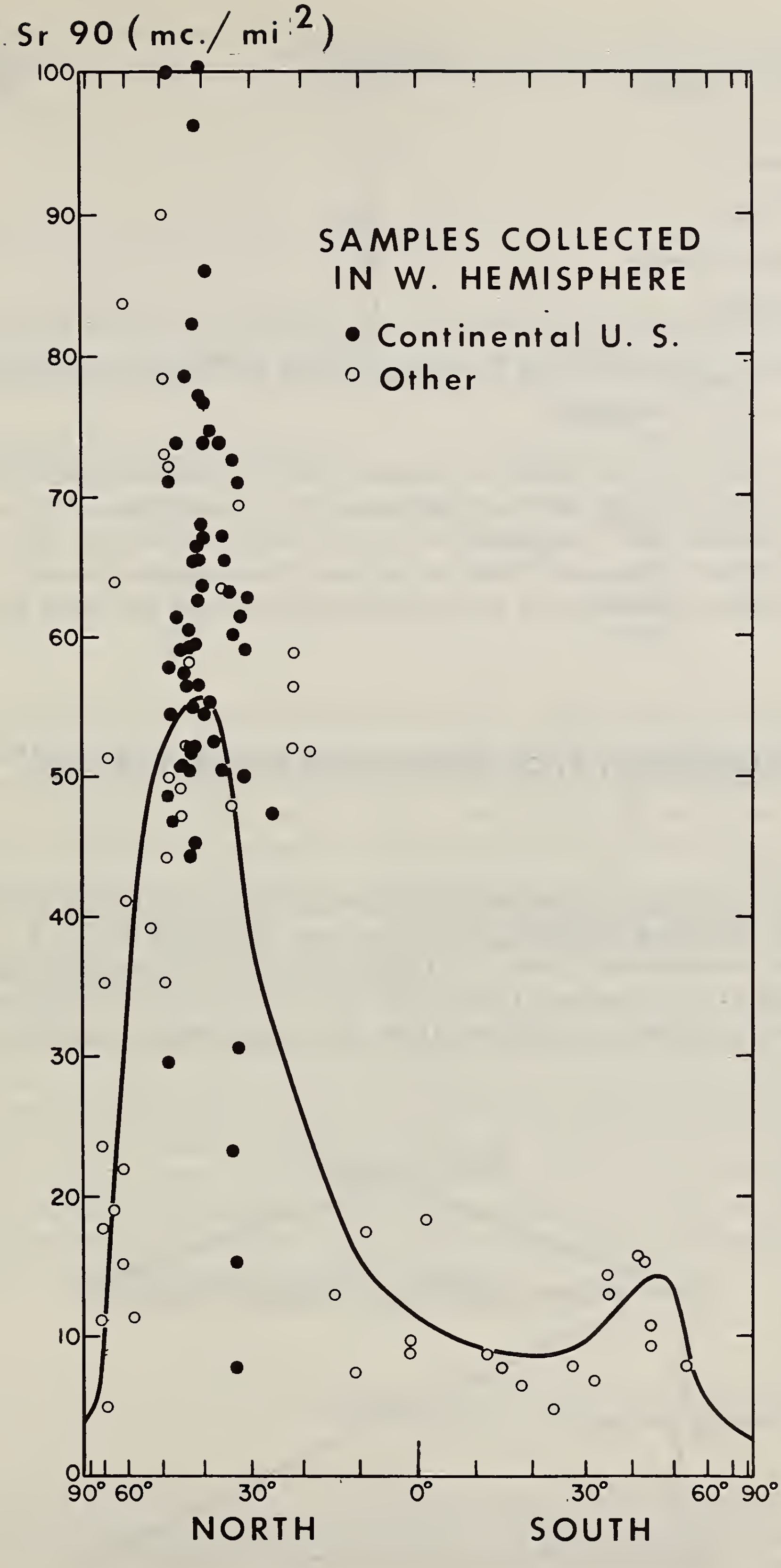

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Figure 39.—Strontium 90 distribution in the Western Hemisphere by latitudes.

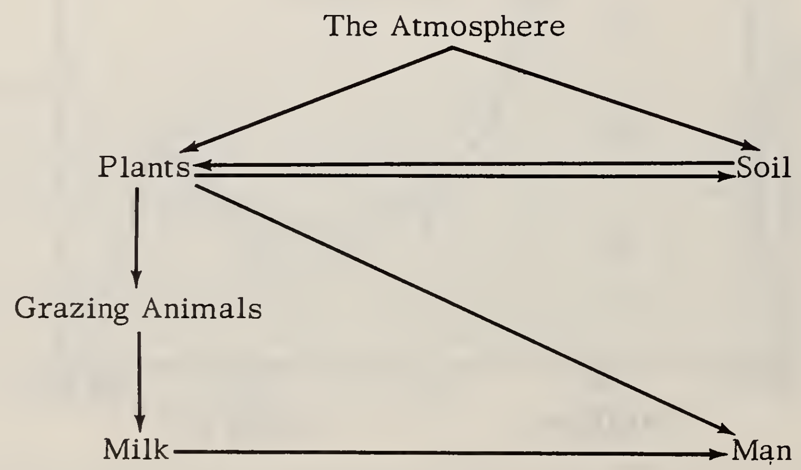
Place of Soil Sample	Precipitation, Inches	mc Sr^{90} per sq. mi.
Forks, Wash.	116	100
Clallam, Wash.	70	71
Port Angeles, Wash.	25	58
Seguim, Wash.	16	30

If the scale used in Fig. 38 is changed to mc Sr^{90}/mi^2/inch of precipitation, a very similar curve is obtained.

There is some wind and water movement of fallout after it reaches the soil. Data obtained from erosion test plots at LaCrosse, Wis., and Tifton, Ga., showed that 99 percent of the fallout Sr^{90} remained on the soil where it fell, but the Sr^{90} that ran off was concentrated 10 times. Thus, in regions of soil accumulation, Sr^{90} could be found in quite high concentrations compared to the average for large areas.

EMERGENCY FOOD PRODUCTION AND WATER USE[1/]

The chain of carriers of radioactive fission products from the atmosphere to man is shown in the following diagram, which has been published by Dr. R. Scott Russell. Since it takes considerable time for fission products to pass through the soil into plants, the pathway including soil is called the long food chain, and that in which plants are contaminated directly by fallout from the atmosphere is called the short food chain.



1/ Prepared by Ronald G. Menzel, Soil and Water Conservation Research Division, Agricultural Research Service, U. S. Department of Agriculture.

For short-lived isotopes, such as iodine 131, only the short food chain is important. For long-lived isotopes, such as strontium 90, both food chains must be considered.

Iodine 131

The estimated amounts of iodine 131 that would be deposited on the land in the first few days after an attack are as follows for various fallout zones.

Roentgens Per Hour at H + 1	mc I^{131} per acre
1	80
3	240
10	800
30	2400
100	8000

It is also estimated that one-fourth of the I^{131} which falls out would be retained initially on pasture vegetation, and that one-twentieth of the amount ingested by cows is secreted in the milk. Thus, from a fallout zone where the gamma radiation intensity at H + 1 would have been only 1 r/hr, the milk produced from 1 acre of such pasture might be expected to contain 1 millicurie of I^{131}. If one acre of pasture provided a day of grazing for 3 cows and they produced 50 quarts of milk, then each quart would contain 20 microcuries of I^{131}. Adults might drink such milk without serious damage, but children should not drink milk containing more than 1 microcurie of I^{131} per quart in order to avoid thyroid injury.

Decay of I^{131} will quite rapidly reduce the hazard from this source. Thus, if milk can be condensed or dried, and stored for 35 days, that which originally contained 20 microcuries would contain only 1 microcurie. Subsequent grazing on the same pasture areas would give lower amounts of I^{131} in the milk, because of the previous removal of I^{131}, and possibly because of the washing action of rains. If the contaminated pastures could be clipped and only the new growth grazed, or if rains or sprinkler irrigation could be allowed to wash off some of the contamination before the pasture was grazed, the I^{131} content of milk would be reduced.

Strontium 90

The strontium 90 content of a crop depends on the amounts taken up from the atmosphere and from the soil. Uptake from the soil will predominate on heavily contaminated lands following a nuclear attack with megaton weapons. However, those areas relatively free of local fallout would continue to receive atmospheric fallout of strontium 90, and this would be the chief source of crop contamination for several years.

Food contamination due to uptake of strontium 90 from the soils can best be estimated by using strontium 90 and calcium ratios. The ratio of strontium 90 and calcium in plants is proportional to that in the soil. The ratio in animals is proportional to that in their diet. These ratios have been called observed ratios, discrimination factors, or distribution factors.

In soils, only the strontium 90 and calcium that is available to plants should be included in the ratio. This includes practically all of the strontium 90, but only the exchangeable calcium in the soil occupied by plant roots. The ratios in green plants average about 0.7 of the ratios in soil. The observed ratios in seeds and fruits average about 0.5. In practice, the observed ratios can be modified by changing the location of strontium 90 and available calcium with respect to the plant roots.

The ratios in meats are about 0.25 of those in the animals' diets. The ratios in milk and eggs are about 0.15 of those in the animals' diets. Since much of the animals' diets consists of green plants, the observed ratios with respect to soil are about 0.2 and 0.1, respectively.

The estimated amounts of strontium 90 that would be deposited on the soil in the first few days after an attack are, as follows, for various fallout zones.

Roentgens Per Hour at H + 1	mc Strontium 90 Per Acre
30	2.5
100	6.6
300	15
1000	37
3000	110

For an attack in which the explosive power of 500 megatons of TNT was produced by fission, which was postulated in the 1958 Operation Alert, the delayed fallout of strontium 90 during the first year would be about 0.5 millicurie (mc) per acre. This would decrease considerably in succeeding years.

The available calcium content of soils can be calculated for each crop from a knowledge of exchangeable calcium content through the root zone. For most crops, the top 8 inches of soil furnishes the calcium. With abundant moisture, many grasses get the bulk of their calcium from less than 4 inches of soil. Some crops in deep soils obtain significant amounts of calcium from depths below 12 inches.

The expected strontium 90 content of a diet produced on a soil contaminated with 8 mc of strontium 90 per acre will now be calculated. Assume that the crops obtain calcium from the top 8 inches of soil, which contains 10 milli-equivalent (meq.), (200 mg.), of calcium per 100 grams. Since the 8 acre inches of soil weigh about a million kg., the strontium 90 and calcium ratio in the soil is about 4 micromicrocuries per milligram. Multiplying the ratio in soil times the distribution factor for each food group gives the expected ratio in that food group. In order to find the ratio of strontium 90 and calcium in the diet, it is necessary to sum the contributions from each food group (Table 1.) When this is done, it is found that the ratio in this diet is just

TABLE 1.—Strontium 90 content in the average daily diet of U.S. adults, if all food items are produced on soil containing 4 micromicrocuries (μμc) of strontium 90 per milligram (mg.) of calcium.

Food group	Observed ratio	Sr^{90}/Ca in food group (μμc/mg.)	Contents in average daily diet	
			Ca (mg.)	Sr^{90} (μμc)
Milk and other dairy products	0.1	0.4	808	323
Eggs	.1	.4	28	11
Meat and poultry	.2	.8	26	21
Leafy, green, and yellow vegetables	.7	2.8	51	143
Cereal and other plant products	.5	2.0	157	314
Content in total diet			1070	812

about equal to the ratio of 800 micromicrocuries of strontium 90 per gram of calcium. Approximately 1 gram of calcium is consumed in the average daily diet and the maximum permissible intake of strontium 90 recommended by the National Committee on Radiation Protection is 2,000 micromicrocuries for occupational exposure.

This same ratio would be obtained with 20 mc of strontium 90 per acre on soils containing 25 meq. of Ca per 100 grams, and with only 2 mc of strontium 90 per acre on soils containing 2.5 meq. of Ca per 100 g. If milk could be obtained free of contamination, the diet would contain 489 micromicrocuries of strontium 90. More heavily contaminated lands, up to 16 mc of strontium 90 per acre on soils containing 10 meq. of Ca per 100 g., could be used without exceeding 800 micromicrocuries in such a diet. Eggs and meat in Table 1 contribute only 32 micromicrocuries of strontium 90. If all other foods were free of contamination, eggs and meat could be produced on very heavily contaminated land, up to 250 mc of strontium 90 per acre on soils containing 10 meq. of Ca per 100 g. Actually, it would not be possible to obtain other foods free of contamination because the delayed fallout of strontium 90 would be deposited in all parts of the country.

We may estimate the importance of delayed fallout in food contamination from an equation proposed by Dr. R. Scott Russell:

$$C = a\,D_p + b\,D_t$$

C is the strontium 90 content of the harvested crop, which should be expressed in terms of millicuries per acre for this purpose. D_p is the amount of strontium 90 deposited during the life of the plant, and D_t the total strontium 90 in the soil, both in millicuries per acre. The coefficients a and b are the fractions of each source of strontium 90 entering the crop. They have been determined for very few crops under field conditions, but ''a'' appears to be usually 5 to 20 times as great as ''b''. For example, if the strontium 90 content of the soil is 1 mc. per acre, then the amount of strontium 90 fallout during the cropping season would be 0.2 millicuries per acre, and "a" would be 0.04 and "b" would be 0.004. Then the strontium 90 content of the crop is (0.04) (0.2) + (0.004) (1) = 0.008 + 0.004 = 0.012 millicuries per acre. If all the conditions are the same except that the strontium 90 content of the soil is 20 mc per acre, the strontium 90 content of the crop would be (0.04) (0.2) + (0.004) (20) = 0.008 + 0.080 = 0.088 mc per acre. In the latter case, the contribution from delayed fallout is relatively less significant.

The Effect of Fallout on Water Supplies

The fallout on lakes, rivers, and oceans is mixed with relatively large volumes of water and, hence, is not so concentrated as the fallout that lodges in the top few inches of soil, where plant roots are usually concentrated. These waters, other than the salty ones, have flora and fauna that are in need of calcium. Hence, strontium 90 also is taken up and eventually settles out on the bottom of the lake or in the mud of the river. The moving waters also contain soil or rock powder, and these adsorb the strontium 90 so that open waters are not hazards from fallout from atomic tests.

Water that comes from wells or springs has been filtered through soils. The strontium 90 has been largely removed in the process of filtration. For industrial processes that require large volumes of water, containing negligible amounts of radioactivity, open lakes and rivers might pose a problem. From the standpoint of direct effect on man, waters do not constitute a major source of concern. In case of contamination due to warfare, the strontium 90 could be readily removed from drinking water by water softeners or ion exchange resins.

Question

Considering only uptake from the soil, calculate the strontium 90 content of the following diet produced on land containing 10 meq. of exchangeable calcium per 100 g., if the strontium 90 levels are 1 mc per acre for animal products and 10 mc per acre for plant products. What will be the strontium 90 content of the diet if fallout on all the land during the growing season is just enough to double the content in animal products?

(Land with 10 mc strontium 90 per acre has 5 micromicrocuries strontium 90 per mg. Ca.)

Food Group	Observed Ratio	Contents in Daily Diet mg. Ca	μμc Sr-90	
Milk and eggs	0.1	400	20	40
Meat	.2	20	2	4
Green vegetables	.7	100	350	385
Other plant products	.5	100	250	275
			622	704

Answer: 622 micromicrocuries strontium 90; 704 micromicrocuries.

REDUCING THE EFFECTS OF RADIOACTIVE FALLOUT ON AGRICULTURE IN TIME OF EMERGENCY[1/]

Introduction

There are two principal means by which radioisotopes are introduced into man's environment. The first is the detonation of nuclear weapons. The other is the release of gaseous wastes accompanying an atomic reactor accident or of liquid wastes derived from chemical processing plants.

Agriculture should be prepared with as much knowledge as possible about protection and survival from the effects of these hazards.

Our understanding of the effects of nuclear energy and its associated radiation hazards is steadily growing through research. Research is continually developing knowledge that would help to provide protection. Not only agricultural leaders, but the rural population as a whole must understand how to protect itself against these hazards and how to save, use, and produce agricultural products in areas that have been exposed to radioactive fallout. The major source of radioactive fallout is a nuclear explosion, a good point at which to start our discussion.

Nuclear Explosion

When a nuclear weapon is detonated, it is accompanied by four destructive phenomena - blast, heat, initial radiation, and residual radiation. The first three are almost instantaneous while the fourth - residual radiation - produces its effects later and over a much longer period. (Fig. 40.)

The area of destruction resulting from the blast, heat, and initial radiation will vary with the size of the bomb, the height of the explosion, and - to some extent - the

1/ Prepared by Frank A. Todd, Office of Administrator, Agricultural Research Service, U. S. Department of Agriculture.

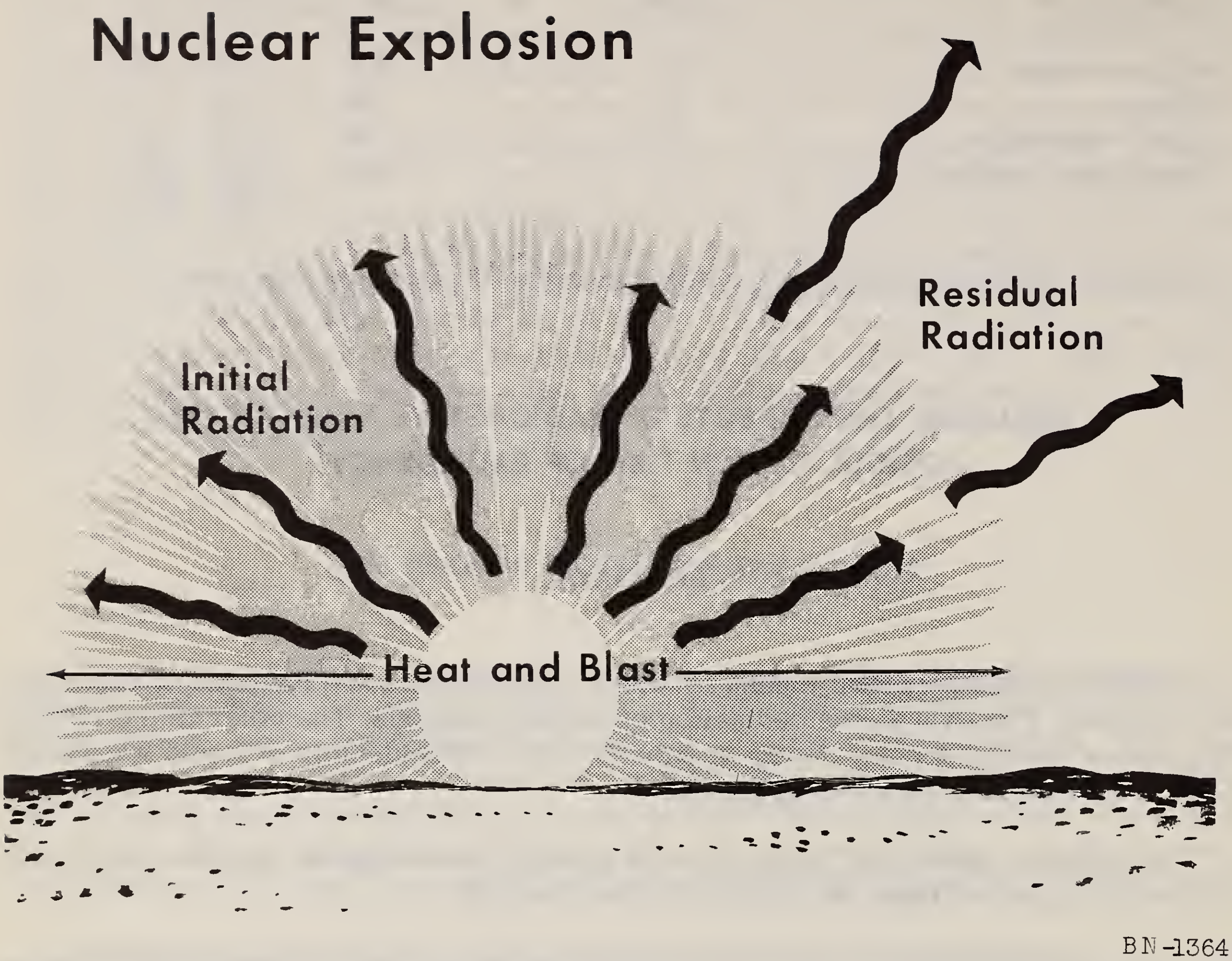


Figure 40.

terrain and atmospheric conditions. The sizes of the large bombs developed since World War II are expressed in terms of megatons. A one megaton bomb has the energy equivalent of 1 million tons of TNT.

When a nuclear explosion occurs, a huge, intensely hot fireball is formed immediately. The temperature of this fireball rivals that of the sun—millions of degrees Fahrenheit. All of the bomb materials within this fireball are, of course, vaporized. This highly heated fireball promptly begins to rise. When the nuclear explosion occurs close to the ground thousands of tons of earth and other materials in the immediate area of detonation are carried aloft and mixed with the hot gases of the atomic cloud. In this cloud some of the earth and debris are melted or vaporized. As these condense and solidify during cooling, they entrap radioisotopes formed from the bomb materials, and the resulting particles are thereby made radioactive. Other particles, which were not melted or only partly melted, may collect radioisotopes on their surfaces. Those particles which are subsequently deposited on the surface of the earth are called fallout.

The heavier bits of debris begin falling in the immediate area shortly after the detonation and may continue for several hours depending on the meteorological conditions. (Fig. 41.)

Fallout

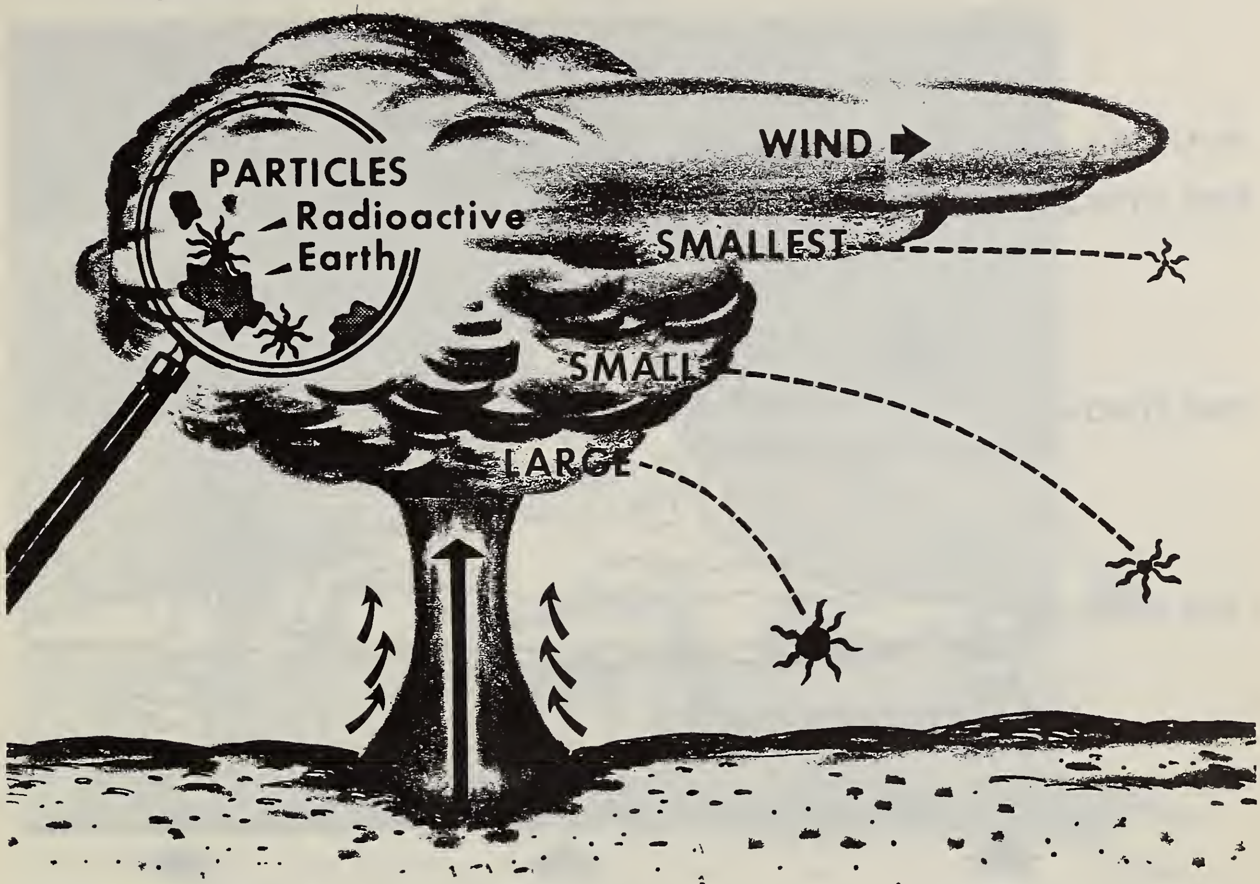


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Figure 41.

According to estimates, about one-half the fallout from an atomic explosion will return to the earth's surface in about 12 hours. The rest descends gradually over days to weeks and extremely small particles carried above the troposphere into the stratosphere may not reach the earth for years. The size of the fallout particles, together with the wind, rain, and other atmospheric conditions, will determine largely when and where they will fall to the earth's surface. The return of the smaller sized radioactive material to the earth is rather slow, mostly carried by rain. When fallout is heavy in an area it creates serious radiation problems. (Fig. 42.)

In very general terms the region of severe local fallout contamination can be described as an elongated or fan-shaped area extending downwind from the point of burst. The pattern will be extremely irregular in outline and contamination within the area is usually not uniform. There may be local areas of extreme danger, others with very little contamination, and all gradations in between. These variations result from differences in topography and local air currents, rain, and other weather conditions.

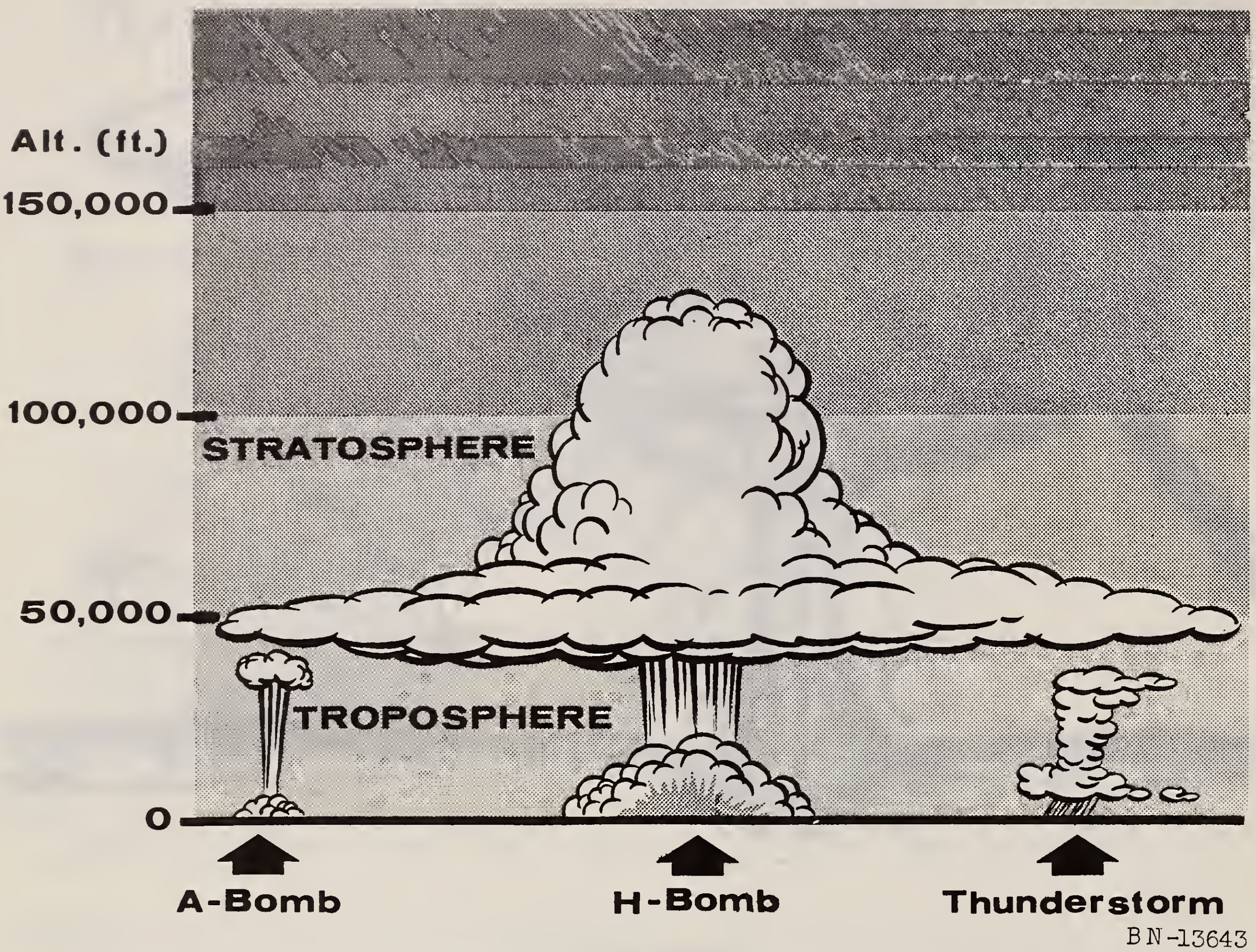

Figure 42. — Cloud altitudes.

Nuclear Radiation

The danger of radioactive fallout is from the nuclear radiation emitted by radioisotopes produced by the explosion of the bomb. This radiation can pass into and through matter. When it does, it can change, damage, or destroy living cells through ionization - the production of electrically charged particles from cell constituents.

In living tissue this ionization may result in the production of active radicals, in dissociation, and in chemical changes, such as the denaturation of protein molecules, splitting of large molecules into smaller ones, and the inactivation of enzymes. Ionization may also result in the formation of toxic molecules like hydrogen peroxide, organic peroxide, and other deleterious substances.

Furthermore, cells may lose their ability to divide and grow, thus inhibiting normal cell replacement in the body. (Fig. 43.)

Nuclear radiation can therefore damage or affect both living and inanimate matter, but it does not transmit the radioactivity to the affected matter. In our problem, the radioactive contamination is in the fallout itself. Once it has been removed,

Radiation Damage
(Ionization)

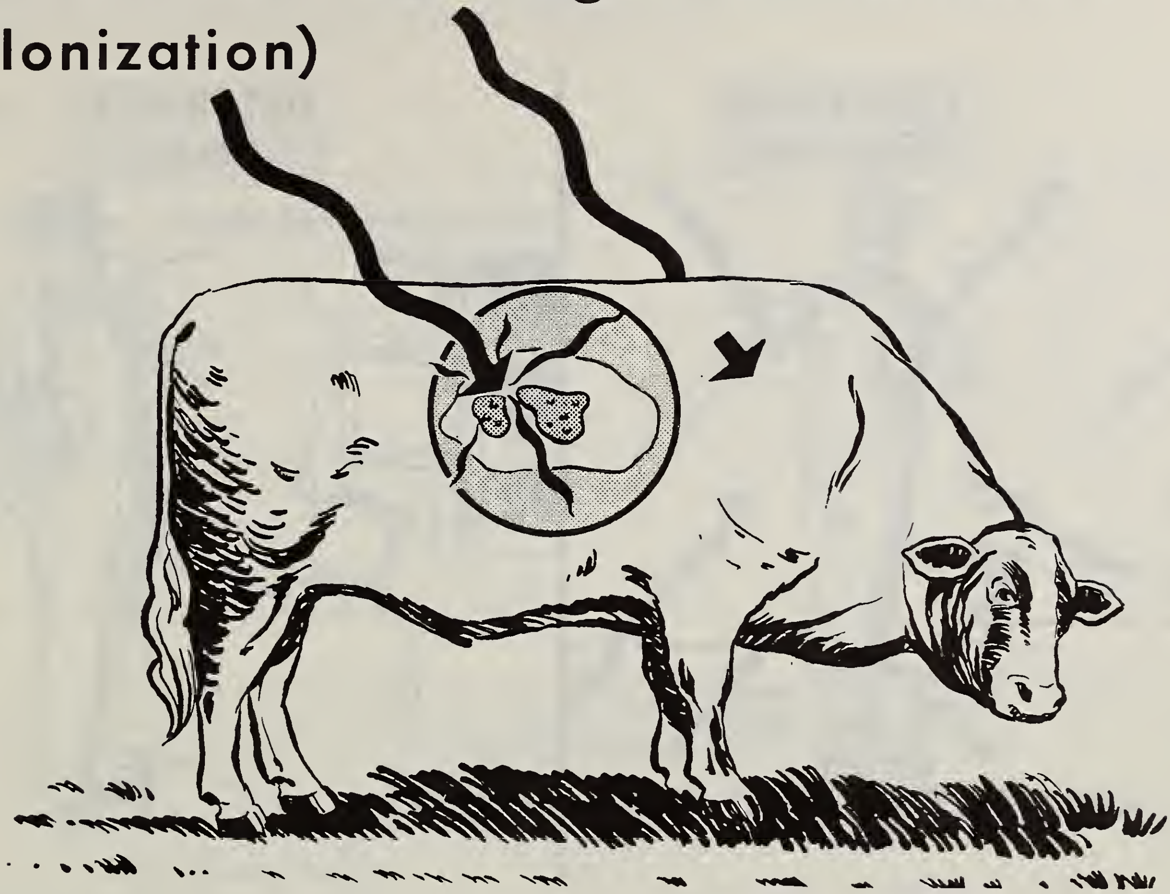

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Figure 43.

the irradiated materials are not contaminated thereafter, but the radiation damage to the living matter may persist or may not appear until later.

We are most concerned, of course, about the harmful effects of ionizing radiation produced in the cells of living tissue and biological systems. There are two types of hazards to animal tissue created by radioactive fallout materials: (1) External and (2) internal. (Fig. 44.)

The initial hazard with which we are faced when fresh fallout arrives in an area is external radiation. The most hazardous external radiation consists of gamma rays, which are similar to X-rays — very penetrating and capable of traveling long distances from their source. The shorter lived isotopes are the chief producers of gamma rays. Our major problem, at this time, would be protection against these rays. The intensity of gamma radiation from fallout decreases in time through a process known as radioactive decay.

Internal radiation is the serious and long-lasting problem created largely by the consumption of contaminated food and water. Although initially the short-lived isotopes producing gamma rays can contaminate food and water, this hazard is caused

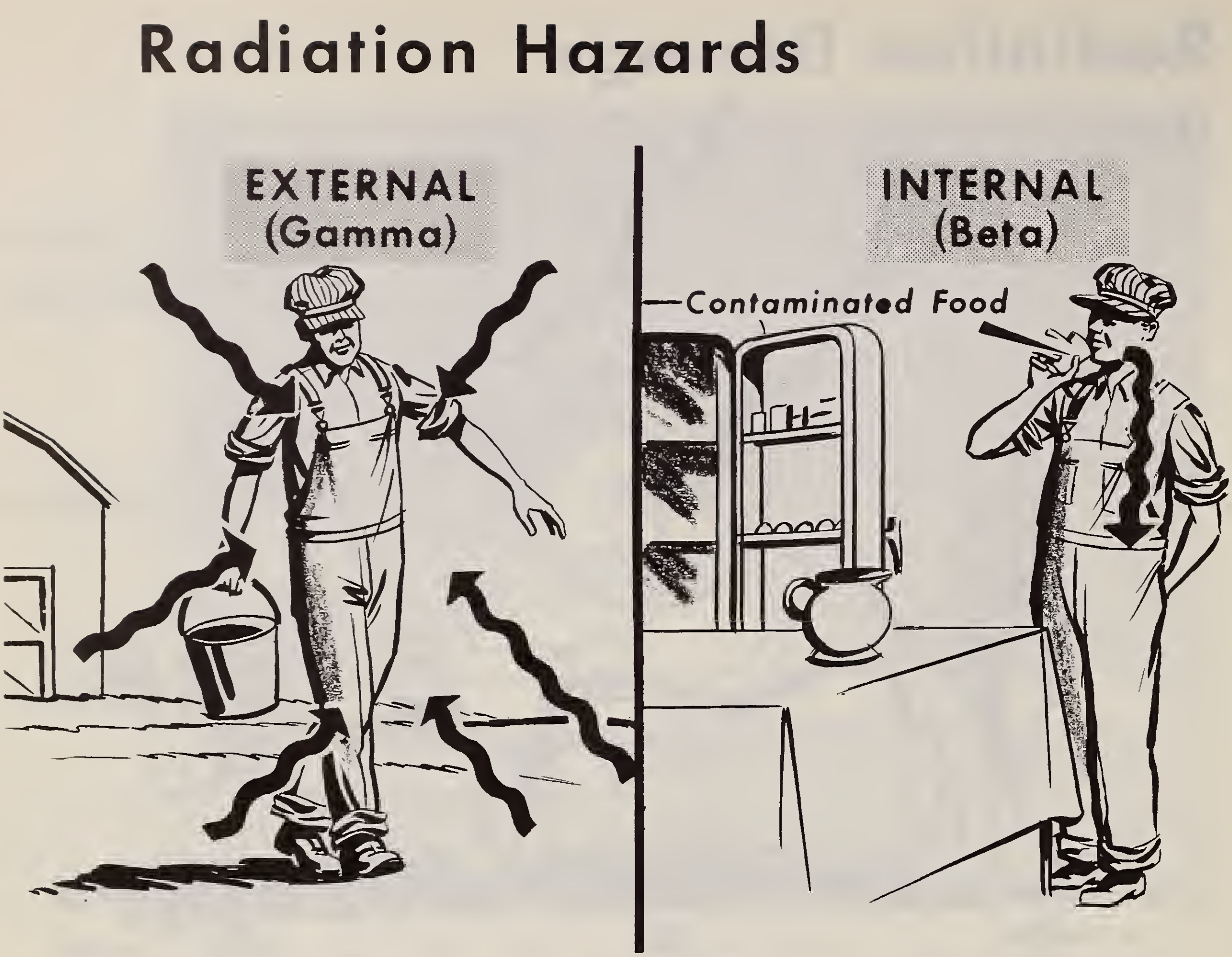

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Figure 44.

chiefly by longer lived isotopes that produce beta rays, which are capable of traveling only short distances. Once inside the body, however, they can continue to damage the cells with which they come in contact. This radiation hazard is of major concern to agriculture since it can affect most food commodities.

Protection against both types of hazard is available.

Protection from Radiation

There are four basic principles of radiation protection: Distance, time, shielding or shelter, and decontamination.

Distance

The first natural protection is distance. As would be expected, the radiation exposure from a nuclear explosion or from fallout is less the farther away you are

from the point of the burst or the source of radiation. This is true because the radiation is spread through larger and larger volumes and absorbed by air and building materials as it travels away from the original point.

Time

The lapse of time is another natural form of protection against radioactive fallout. The total radiation hazard of the fallout begins to decrease the very moment it is formed. The various radioactive elements included in the fallout cloud decay at different rates, usually expressed in terms of their half-lives. Some isotopes lose half their radiation strength within seconds, hours, or days. Others decay at a much slower rate. For example, iodine 131 has a half-life of 8 days, while strontium 90 has a half-life of 28 years. In other words, iodine 131 has decayed to half its strength in 8 days (Fig. 45) while it takes 28 years for strontium 90 to lose half its original radioactivity. Therefore, the total radioactivity of fresh fallout decreases rapidly at first, but the rate of decay slows to a very low value after the shorter lived elements have lost their radioactivity. (Fig. 46.)

A rule of thumb has been developed to estimate the decay rate of the mixture of all isotopes developed from a nuclear explosion. This rule states that for every

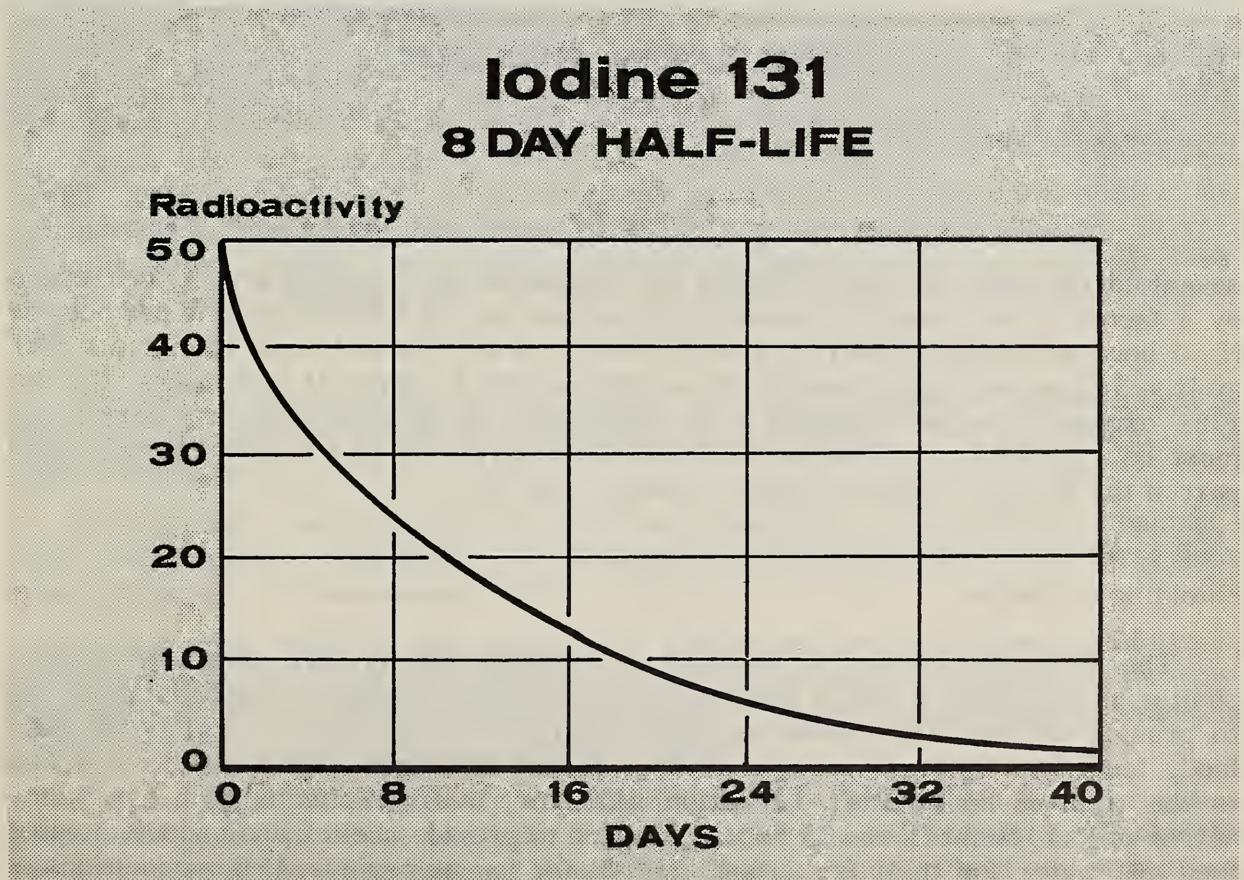

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Figure 45.

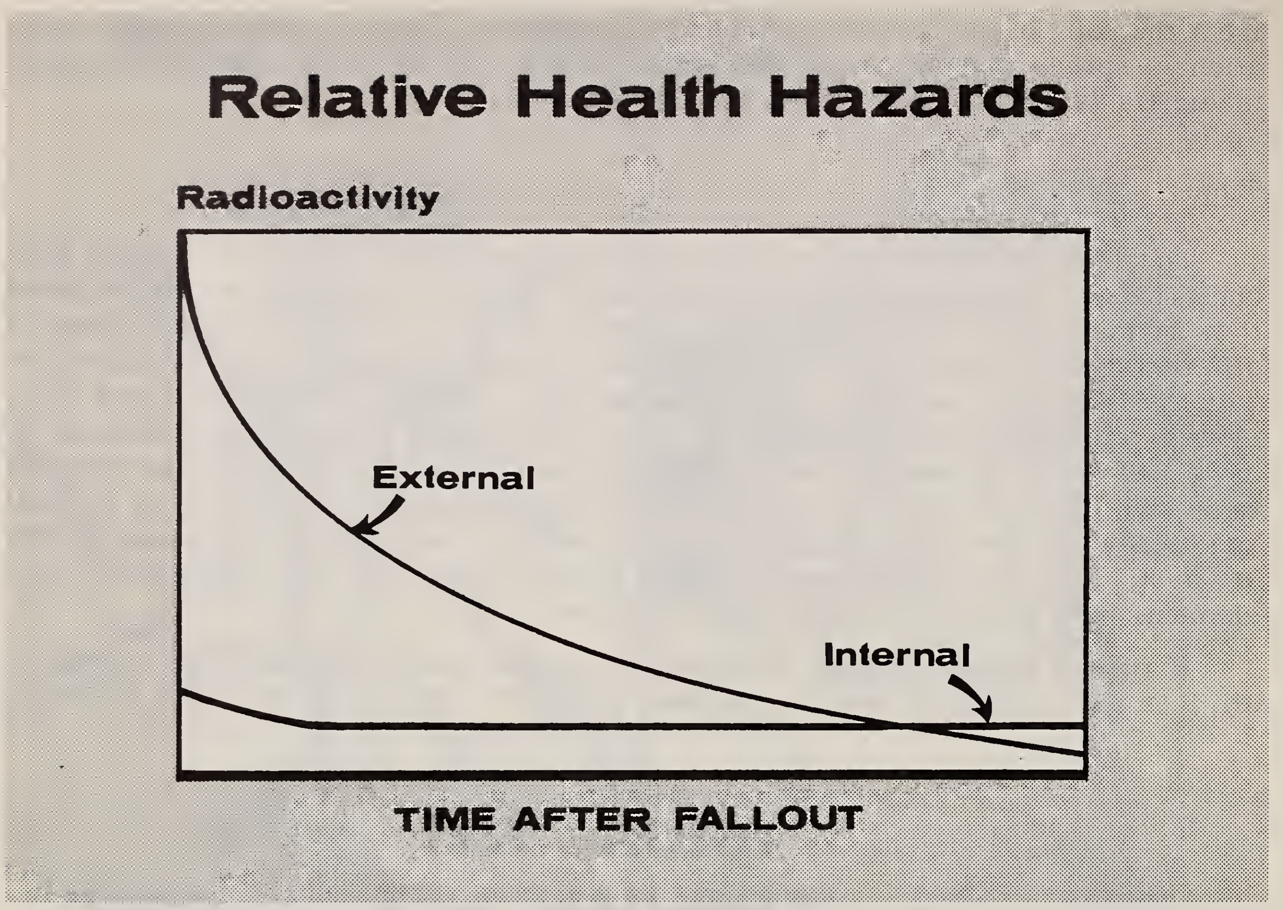

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Figure 46.

sevenfold increase in time following the detonation the radiation activity decreases by a factor of ten. Using this assumption, a dose rate of 1,000 roentgens per hour at H + 1 hour will decay to 100 r/hr at H + 7 hours, to 10 r/hr at H + 49 hours, to 1 r/hr at H + 343 hours (approximately 2 weeks) and to 0.1 r/hr at H + 14 weeks. The 0.1 r/hr exposure can be accepted in an emergency as relatively safe for work which must be carried on out-of-doors. This would result in about 1 r/day exposure since part of the 24 hours would be spent indoors. (Fig. 47.)

Shielding or Shelter

The third protection is shielding or shelter. The primary object of a fallout shelter is to provide a shield against gamma radiation. Farmers should be prepared to provide shelter from fallout for their families and livestock, as well as for their food, feed, and water. The most critical period of danger from radioactive fallout is the first 48 hours after detonation. However, in areas affected by heavy radioactive fallout, farmers should be in a position to provide shelter and uncontaminated food and water for their family and animals for longer periods. Under conditions of heavy fallout, it would be advisable to stay within shelter - at least most of the time - for as much as a week or two.

Time - Decay

TIME (hr.)	DECAY	RADIATION INTENSITY
1	—	1,000 r/hr
7	1/10	100 r/hr
7X7 = 49 (2 days)	1/100	10 r/hr
7X7X7 = 343 (2 wks)	1/1,000	1 r/hr

BN-13648

Figure 47.

There are two methods of reducing radiation exposure. The first method is called "barrier shielding." A barrier is placed between the source of radiation and the individual. The thicker and denser the protective barrier the greater the barrier shielding effect. Walls, floors, and ceilings of buildings can serve as such barriers, but to be very effective must be thick and of dense material such as concrete or brick.

The effectiveness of the second method - geometry shielding - is determined by the extent of the fallout affecting an individual and the distance from the person to the deposits of fallout.

For example, two buildings may be of the same height, and of similar construction - but protection from ground contamination would be greater on the first floor of a building that is substantially wider and longer.

On the other hand, if two buildings of similar construction cover equal areas, but differ in height, protection from roof contamination would be greater on the first floor of the higher building. The combined effects of barrier and geometry shielding result in what is called "shelter protection factor."

The first floor of an ordinary wood framehouse in a fallout area would provide a protection factor of about one-half. That is, you would receive about one-half the radiation dose in the house that you would if you were outside without any protection. In the cellar, your exposure would be appreciably less, only about one-tenth.

An underground shelter with a covering of 3 feet of packed earth would provide a highly effective protection factor. (Fig. 48.)

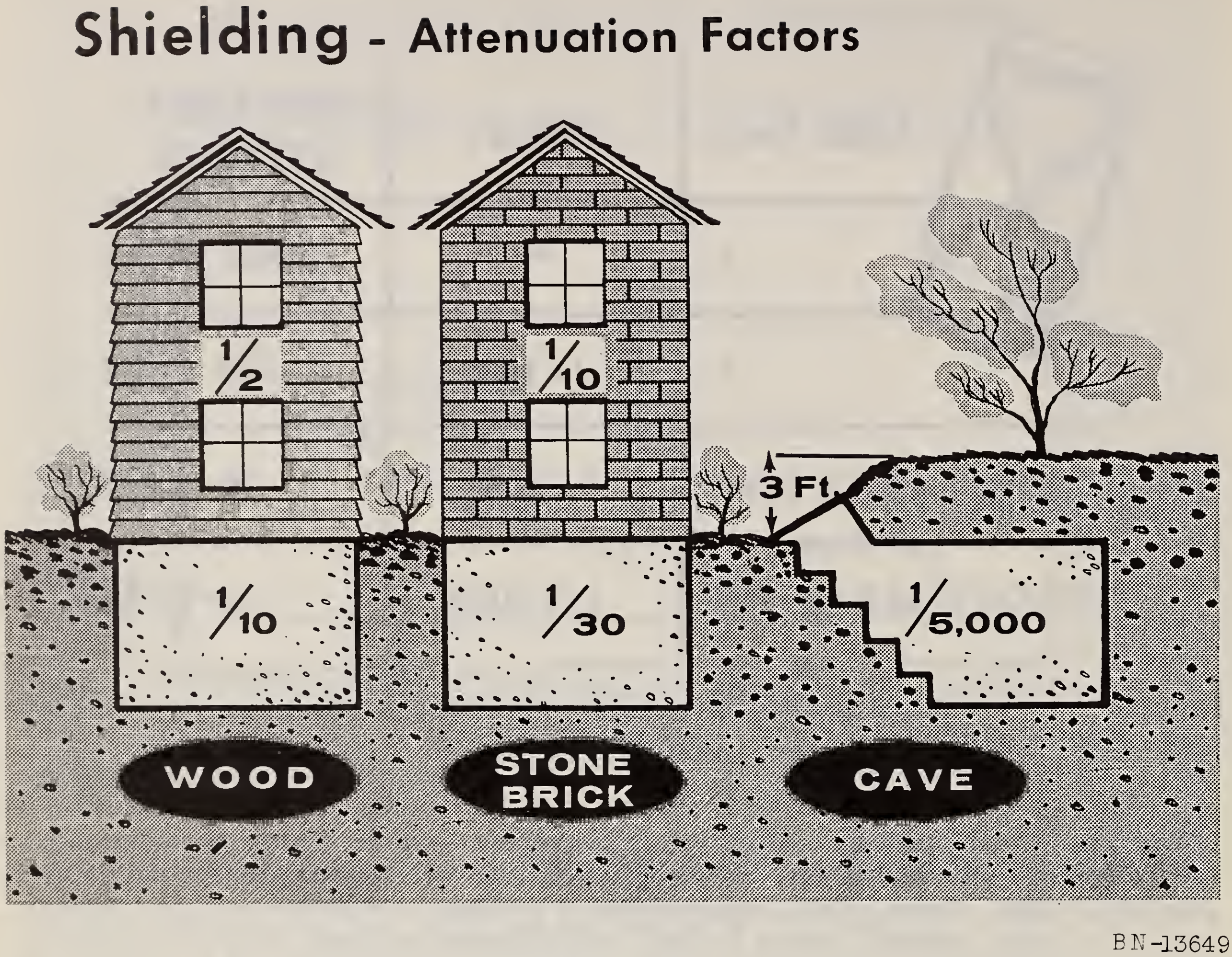


Figure 48.

Decontamination

Decontamination against radioactive materials is unlike that used against a disease outbreak where the causative organism of the disease is destroyed — or in the case of chemical contamination where one chemical is used to neutralize another. Radioactive materials cannot be destroyed.

Therefore, since radioactive materials cannot be destroyed, decontamination involves the transport of the source of radiation (fallout.) The fallout should be removed from a location where it is a hazard to a place where it can do little or no harm. Thus, there are two procedures, removal and disposal. (Fig. 49.)

Farmers' Problems

The farmer has two major responsibilities in the event of a nuclear attack.

First, to provide protection for himself and his family from radiation and fallout. He must provide adequate shelter, food, and water (at least 2 weeks' supply), sanitary

Figure 49.

facilities, and a battery radio or some other means of receiving emergency information.

Second, he should provide protection for his livestock and poultry from radiation and fallout. This protection would include shelter, uncontaminated food and water, and buildings and other facilities for confinement until the radioactivity outdoors decays to a level that would be relatively safe for the livestock to be turned out. (Fig. 50.)

For livestock, a good tight barn would reduce radiation dosage about one-half. Four bales of hay will provide a protection factor of over 4, while 10 feet of loose hay will give about 2.5. But any kind of shelter provides some degree of protection. Proper use of shelter for animals can materially reduce the number of deaths from radiation. (Fig. 51.)

Experiments have indicated that total body radiation exposure of animals to about 550 roentgens provides a midlethal dose - the dose level which you could expect to kill 50 percent of the animals within 30 days. However, there is also a variation of tolerance among species and even breeds of animals.

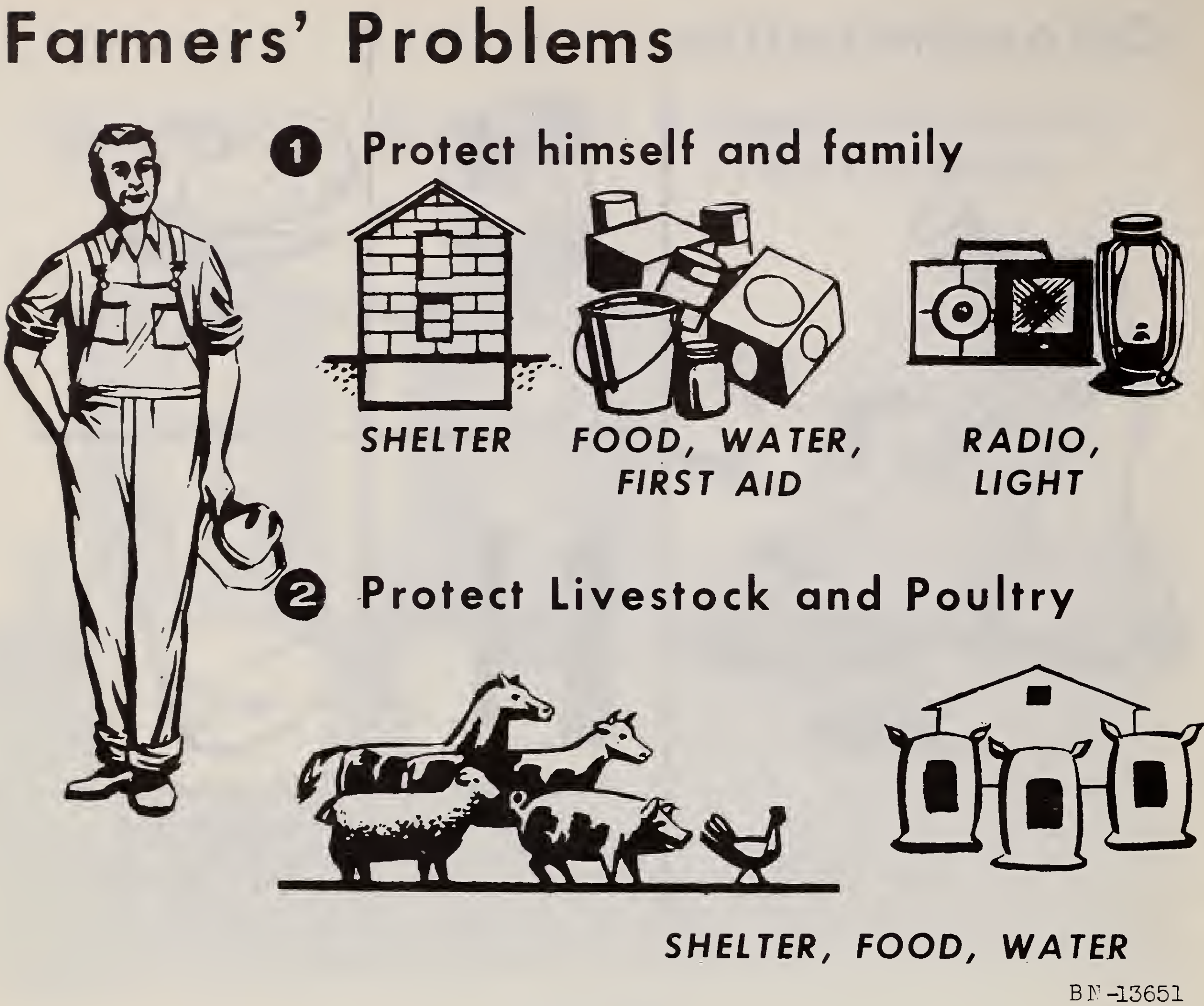


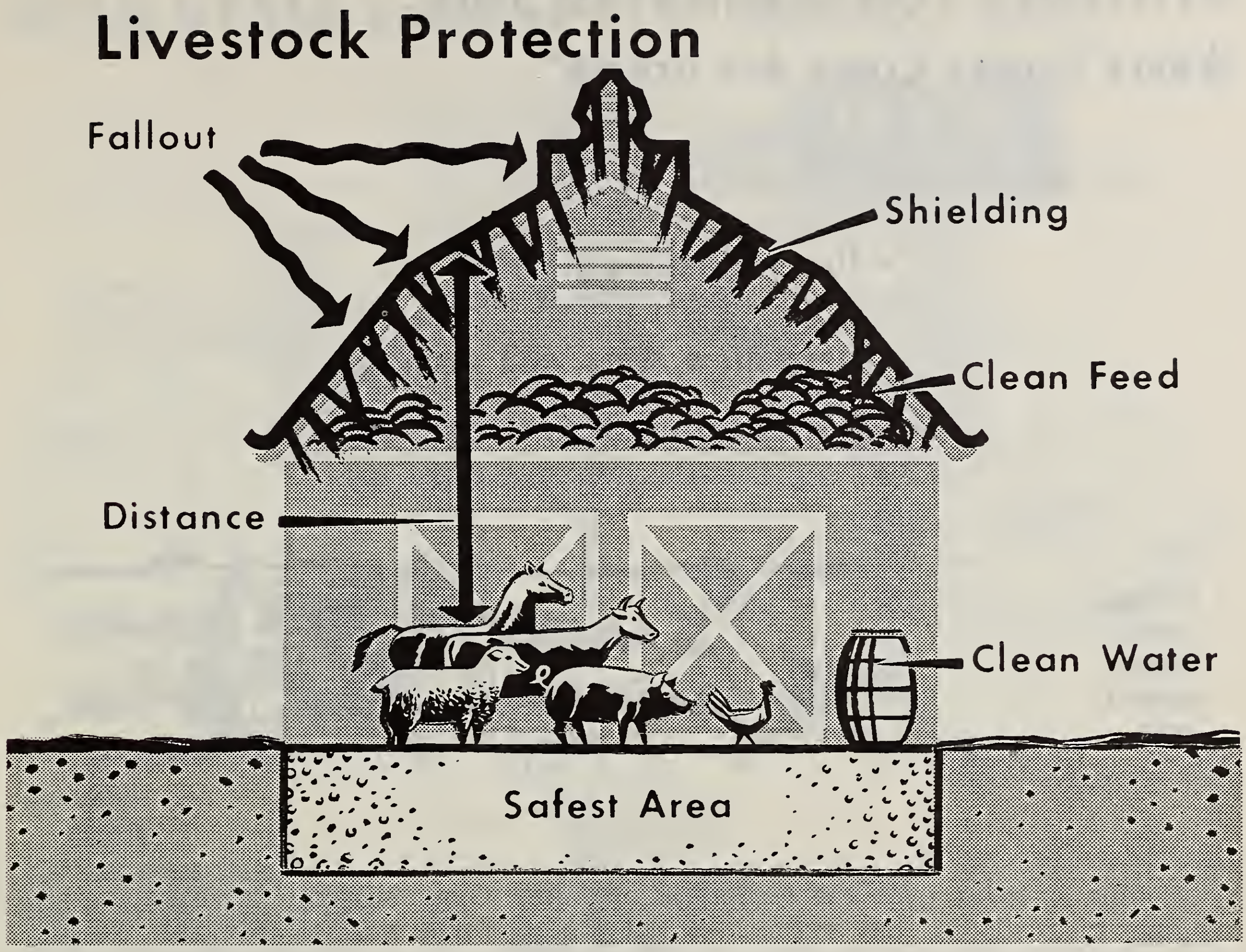
Figure 50.

Table 1 gives the percent mortality of various species of unsheltered animals affected by exposure to different intensities of radiation.

TABLE 1.—PERCENT MORTALITY OF VARIOUS SPECIES OF UNSHELTERED ANIMALS FOLLOWING EXPOSURE TO A 24-HOUR RADIATION DOSE

Species	Mortality 100%	80%	50%	20%	0%
	Exposure Dose in Roentgens*				
Cattle	650	600	550	450	300
Sheep	700	600	525	450	350
Swine	800	700	600	450	350
Poultry	1200	1100	900	600	400

* Exposure dose in area where livestock and building are located.



BN-13652

Figure 51.

Hazards of Internal Radiation

The second phase of radiation hazard from fallout is internal and caused by the long-lived radioactive isotopes, especially those that move through the food chain. These radioactive elements generally enter the bodies of animals and human beings with contaminated food and water.

At first the principal source of internal radiation consists of edible plants contaminated externally when the fallout first drops on the affected area. For livestock this would involve primarily forage grasses and legumes. For man it would involve fruits and vegetables. Growths of alfalfa and other feed crops standing in the fields at the time of the fallout might not be usable. Subsequent growths would be less radioactive. As time passes, and the contaminated food and feed are discarded, the principal source of internal radiation for animals and man is from the contamination in the soil which is absorbed through plant roots. (Fig. 52.)

In protecting feed and water, the objective is to prevent the fallout, which is the source of radiation, from becoming incorporated into the materials. This can be done

UTILIZING CONTAMINATED SOIL

Where Forage Crops Are Grown*

CUT AND REMOVE EXISTING CROP:

- **Use succeeding growths, or...**
- **Deep plow, lime, and reseed**

* ALFALFA
CLOVERS
GRASSES
LESPEDIZA
VETCH

BN-13653

Figure 52.

by placing a cover over the feedstuffs or water. Grain stored in a permanent bin, ensilage in a silo, or hay and feed stored in a good tight barn is provided with adequate protection against fallout and the contents can be safely used when the farmer is able to get into the area to use them. The haystack in an open field can be protected with a covering such as a tarpaulin. The fallout will lodge on the tarpaulin, irradiate the hay - just as it does the contents of the feed bin, barn, and silo - but by carefully removing the tarpaulin, the radioactive fallout will be removed. Although the hay would be irradiated, it would not be radioactive and could be used as a safe source of feed for livestock. (Fig. 53.)

The use of standing crops, such as grain, fruits, and vegetables, subjected to fallout will depend upon the stage of growth; that is, whether they can be allowed to stand until radioactivity has decayed enough to make it relatively safe for workers to harvest them. If fallout is heavy, ripe fruits may be lost because of the personal hazard involved in harvesting them. Fruits that do not have to be picked immediately and that can be peeled before eating, probably can be saved. They can be decontaminated with washing agents before marketing. Orchard trees should be maintained and the fruits examined for radioactivity before and after harvest. Root vegetables such as carrots or potatoes could also be harvested, washed and peeled before use. Leafy vegetables such as lettuce should not be eaten unless they are thoroughly washed and are known to be free of hazardous amounts of radioactivity. Experiments have shown that the thorough washing of leafy vegetables such as lettuce and spinach

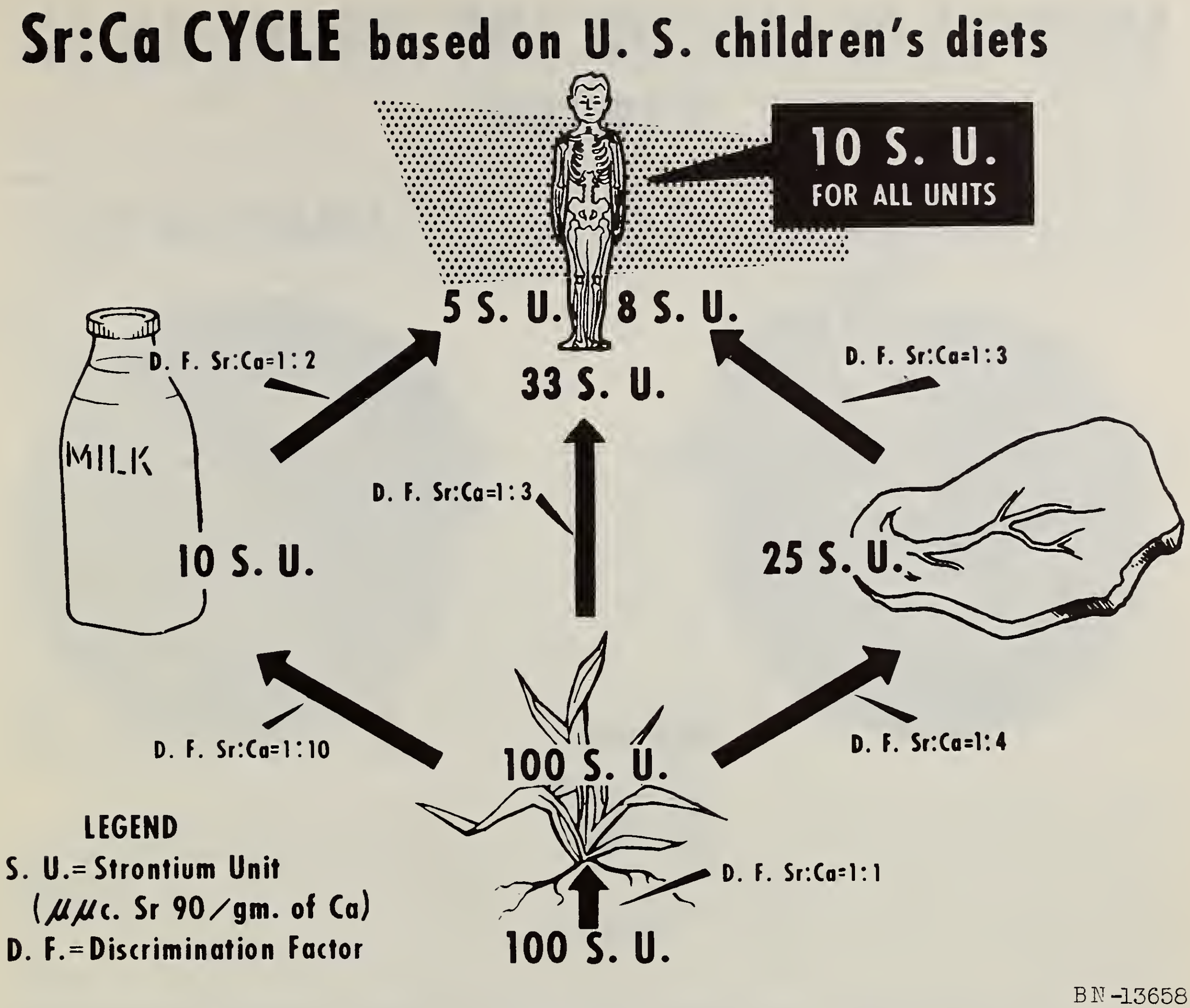


Figure 57.

in our diets, except under conditions of extreme emergency. In fact, the evidence available at this time would indicate that it is better to continue getting more of our dietary calcium from milk and less from plants.

Radioactive isotopes of strontium deposited in the bone probably can produce serious consequences, including bone cancer and leukemia. But since radiostrontium is assimilated in the bones, it constitutes essentially no genetic hazard for its radiations do not reach the reproductive organs to an appreciable extent.

The International Commission on Radiological Protection has suggested that the maximum average daily intake of strontium 90 for a general population be 33 micromicrocuries per liter or kilogram of food. This is based on a 50-year exposure. The National Committee on Radiation Protection and Measurement has accepted this figure as an interim recommendation.

The figure of 33 micromicrocuries per kilogram of food or liter of water was suggested as a conservative guideline for strontium 90 in the human diet. In studying the health hazards of strontium 90, it is essential to consider the amounts consumed

SOURCES OF CALCIUM AND STRONTIUM 90
From Food

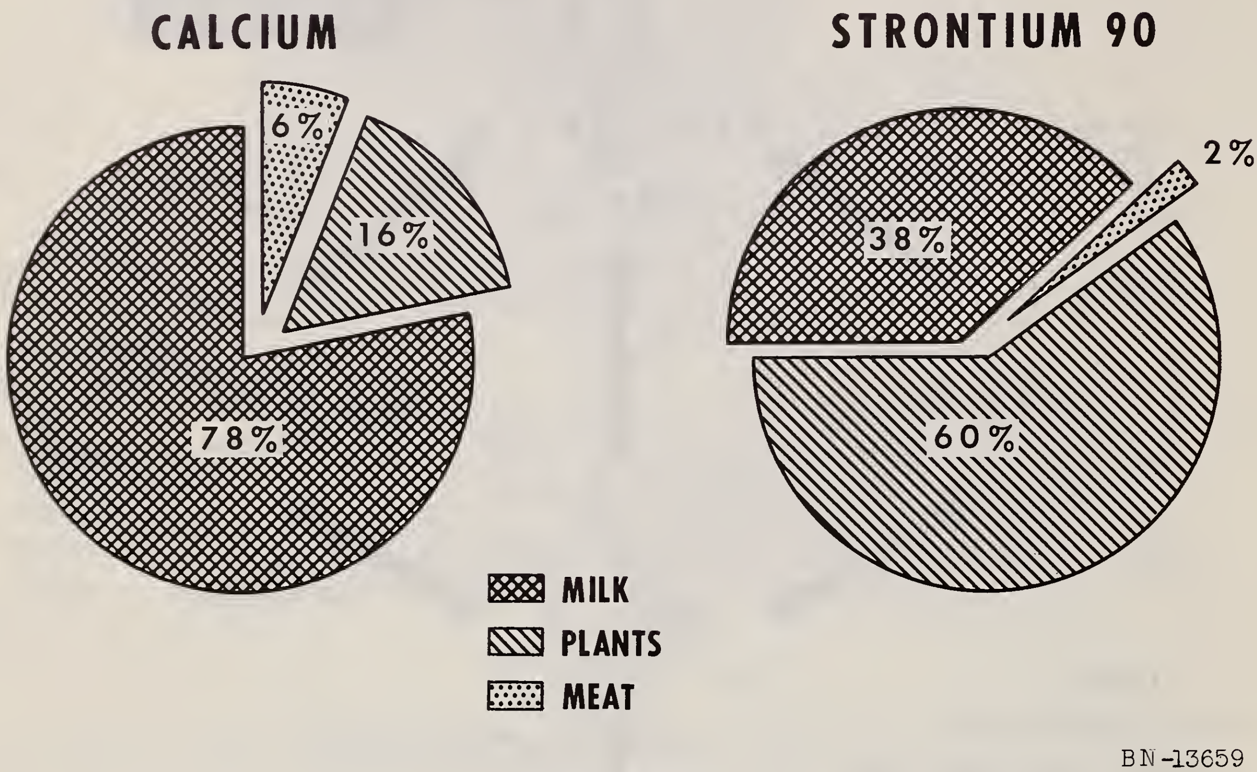


Figure 58.

from all foods and drink. The average American may consume about 2.2 kilograms of food and water daily. Thus the average daily intake of strontium 90 could be 73 micromicrocuries (2.2 kilograms x 33 micromicrocuries).

Human beings under usual conditions constantly receive radiation from many sources. Cosmic rays, potassium, and radium present in earth and bones are a few of these sources. This background radiation contributes about 2 percent of the maximum level adopted by the International Commission on Radiological Protection as acceptable for large segments of the general population. Other sources are X-rays and luminescent watches.

The exact long-term results of chronic exposure to internal radiation created by multi-bursts of modern nuclear weapons, under emergency conditions of an attack on populated areas, are not known.

Federal agencies and laboratories, universities, and agricultural experiment stations conduct research and studies on the effects of radioactive fallout and measures for decontamination. The Department of Agriculture, in cooperation with the Atomic Energy Commission, is conducting investigations on methods of reclaiming radioactive soil for use in the production of food in the event of catastrophic fallout. Among the methods that have been examined or are being studied are (1) diversion to other uses, (2) removal of ground cover, (3) removal of surface soil, (4) liming, and (5) deep plowing.

Diversion of Land and Farming Practices

Diversion of the land to other uses may mean changing the species of crop grown on the land. The quantity of strontium 90 absorbed could be reduced by growing crops with low concentrations of strontium and calcium in their edible tissues. However, since plants are a source of calcium, this measure would result in the calcium content of diets being reduced. Unless alternative sources of dietary calcium were provided, cultivating low-calcium crops would have limitations. However, in wartime emergencies survival might be aided by this procedure. Potatoes and corn, which contain about 10 milligrams of calcium per 100 calories, are particularly suitable crops in contrast to leafy vegetables, which may contain 10 to 100 times that amount of calcium per 100 calories. (Fig. 59.)

If the top several inches of the soil are contaminated with strontium 90, deep-rooted plants may be grown with little uptake of the radioactive material, because they draw their nutrients from below the contaminated layer. (Fig. 60.) For example, contaminated land could be taken out of shallow-rooted forages or crops and be used for producing such deep-rooted crops as alfalfa. Diversion applies also to livestock. Some of the strontium consumed by animals grazing on contaminated pastures goes into the bones or milk. Only a negligible amount goes into the meat parts. Land formerly used for dairying may have to be diverted to beef or other meat production. Another diversion might be to take land out of food production and use it for cotton fiber, flax, castorbeans, timber, or other nonfood production. If the land is too heavily contaminated to be managed, it might have to be taken out of agricultural production for an indefinite period. Care must be taken in disposing of contaminated crops and forage to prevent such materials from being stored where they will be hazardous to man, animals, and food.

Decontamination by Removal of Ground Cover

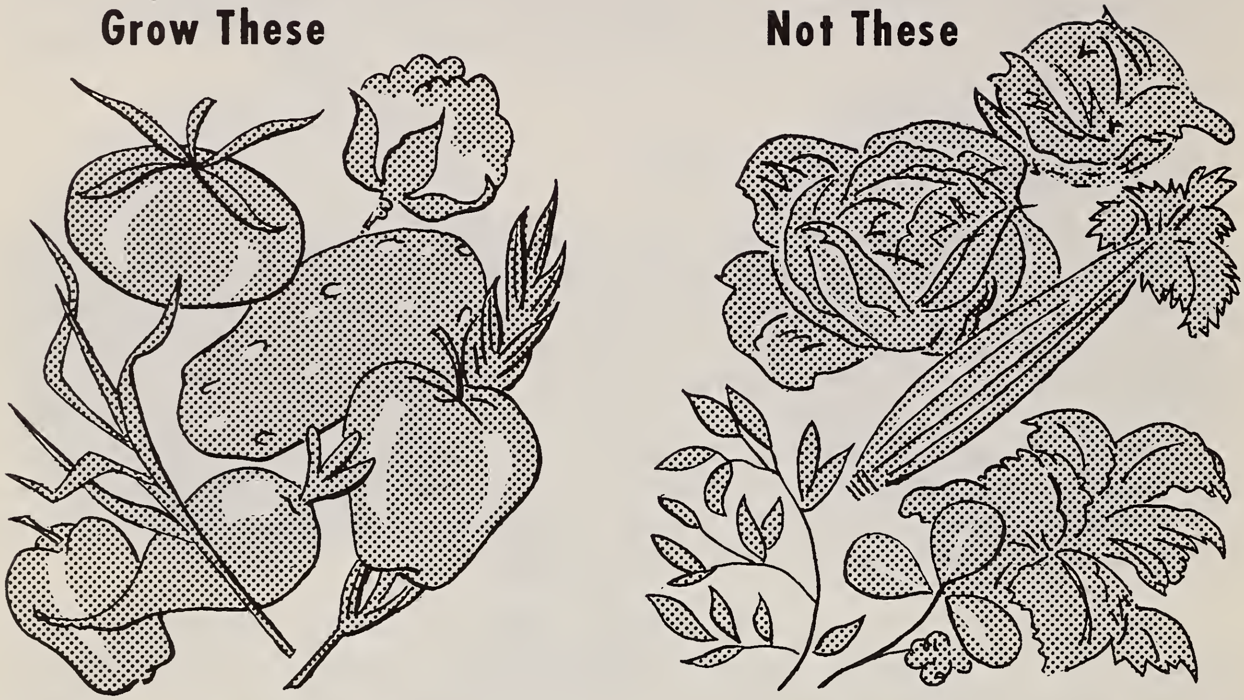
Experiments conducted by the USDA indicate that the radioactive contamination of land can be effectively reduced by the removal of the ground cover. Mulches of various thicknesses have been tested. Effectiveness of mulches depends on the physical size of the fallout particles and, more important, on how completely the mulch can be removed.

Tests and experiments revealed that removal of heavy contaminated mulches, 5 tons per acre, removed from 50 to 80 percent of the radioactivity even following

SUBSTITUTE CROPS
Having Low Calcium Content

LOW
Grow These

HIGH
Not These



Potatoes, cereals, apples, tomatoes, peppers, sweet corn, squash, cucumbers

Lettuce, cabbage, kale, broccoli, spinach, turnip greens, celery, collards

BN-13660

Figure 59.

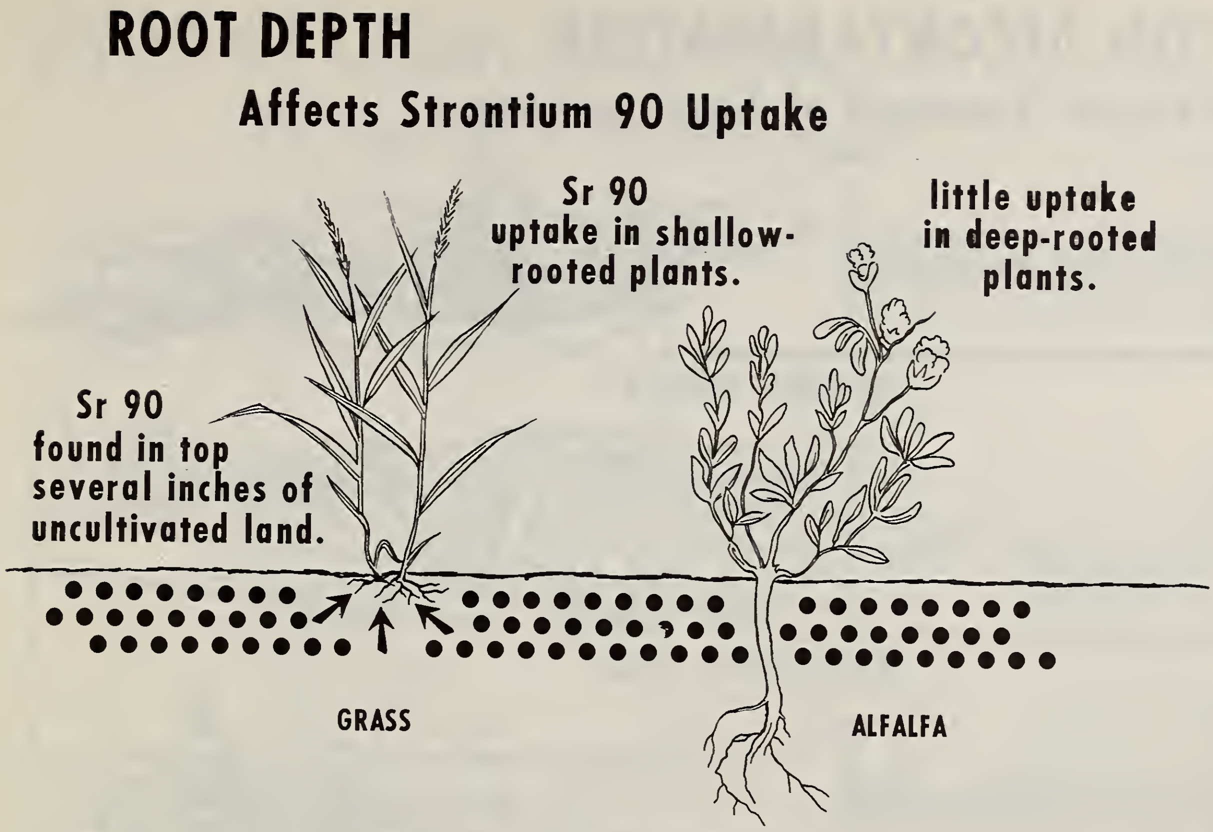
irrigation. Removal of lighter mulches, 2 tons per acre, removed 30 to 50 percent. The cutting, rolling, and removal of sod contaminated with fallout resulted in a reduction of radioactivity by over 90 percent.

Decontamination by Removal of Surface Soil

Removing the contaminated surface soil by scraping has been from partly to highly successful, depending upon the roughness of the land. By carefully removing the contaminated surface and burying the radioactive soil in an isolated area, the land may be reclaimed for some use. The method might be expensive and—with the procedures developed at this time—not suitable for large acreages. It might be useful if small clean areas are seriously needed to produce food for survival. (Fig. 61.)

Reducing Strontium 90 Uptake with Soil Amendments

Additions of lime, gypsum, fertilizers, or organic matter in practical amounts usually reduce uptake of strontium 90 by less than half. Combinations of soil amend-



BN-13661

Figure 60.

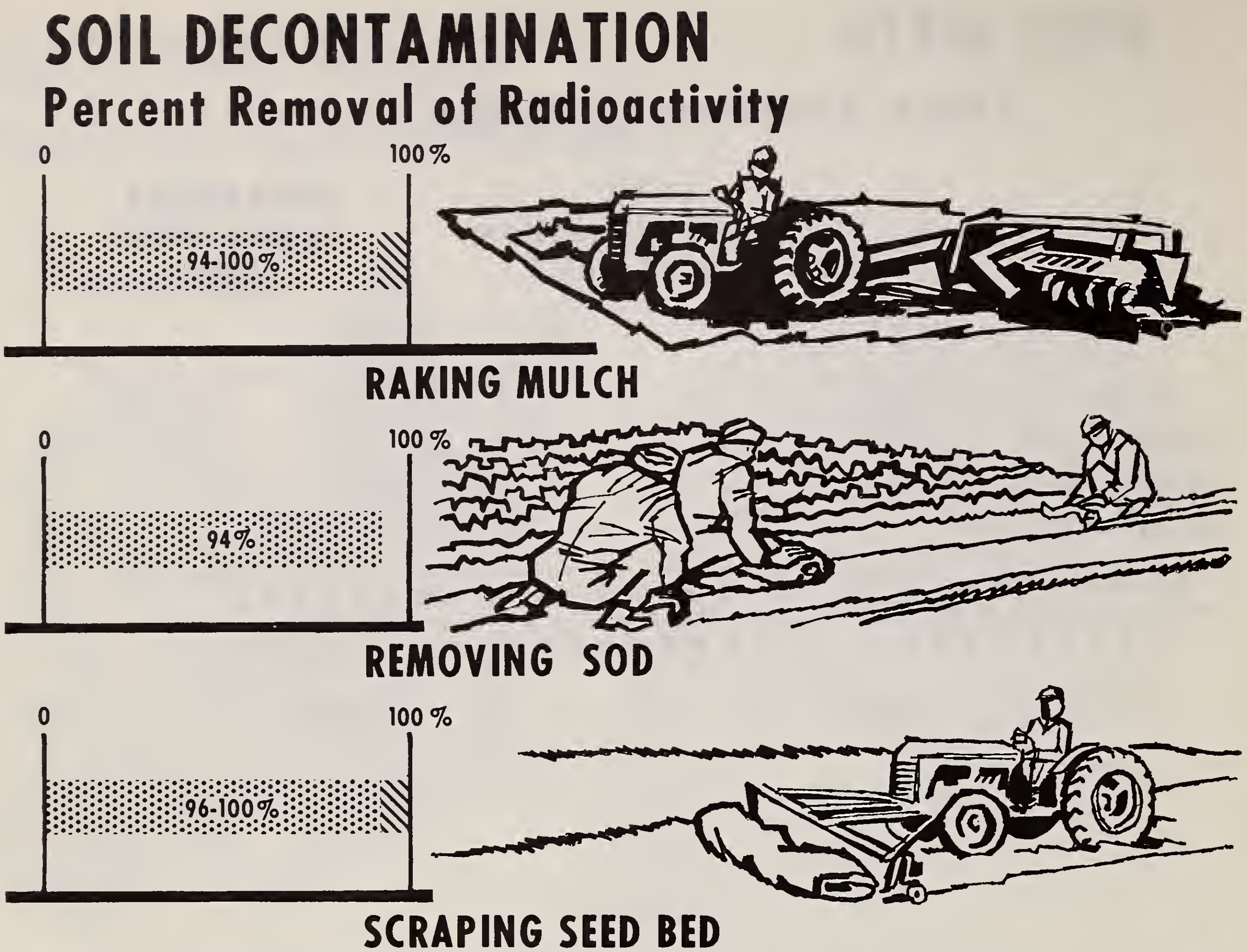
ments and tillage practices may reduce uptake more than any single amendment would. The best use of soil amendments for maximum crop production is generally the same as their best use for reducing strontium 90 uptake.

Diluting Contamination by Liming

Still another method of making contaminated soil more useful to agriculture is the addition of lime. The plant's need for calcium leads to the absorption of the similar element, strontium. In soils low in exchangeable calcium, more strontium 90 will be taken up by the plant. By liming acid soil, more calcium is made available to the plant and less strontium 90 will be absorbed. The practice would be useful on highly acid soils on which liming normally would be beneficial for other reasons. (Fig. 62.)

Reclaiming Soil by Deep Plowing

Deep plowing would be aimed at turning the contaminated surface soil under to a level of one foot or more — or below the root zone of the plants that are to be grown. Deep plowing may reduce the uptake of strontium 90 in shallow rooted crops such as grasses and many vegetables by a factor of about 3. However, before it is used, careful evaluation should be made of the situation in the area and the possible alterna-



BN-13662

Figure 61.

tives. Once strontium 90 has been plowed under, it is in the soil virtually permanently and no method of future removal is known at this time. (Fig. 63.)

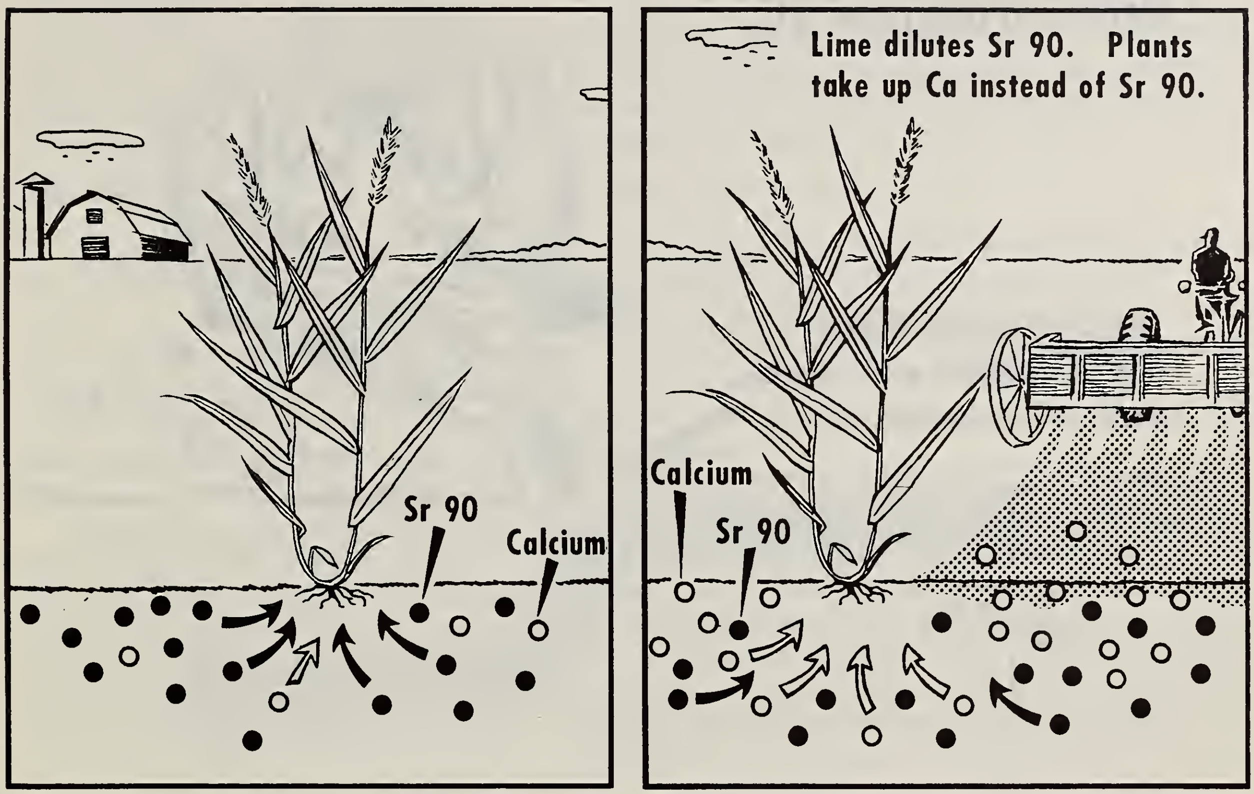
Milk Research

Additional cooperative research between the USDA, the Atomic Energy Commission, and Cornell University includes studies of the response of animals to daily intakes of radioisotopes with particular reference to their movement in the food chain and the resulting pathology. Present work is designed to determine the extent to which radioactive materials ingested by the dairy animal become incorporated and are secreted into the milk. The study also includes possible means of altering this movement and disposition of the radioisotope.

Research on the removal of radioactivity from milk is being conducted cooperatively by the Atomic Energy Commission, U.S. Department of Health, Education, and

EFFECT OF LIMING ACID SOIL

On Uptake of Strontium 90



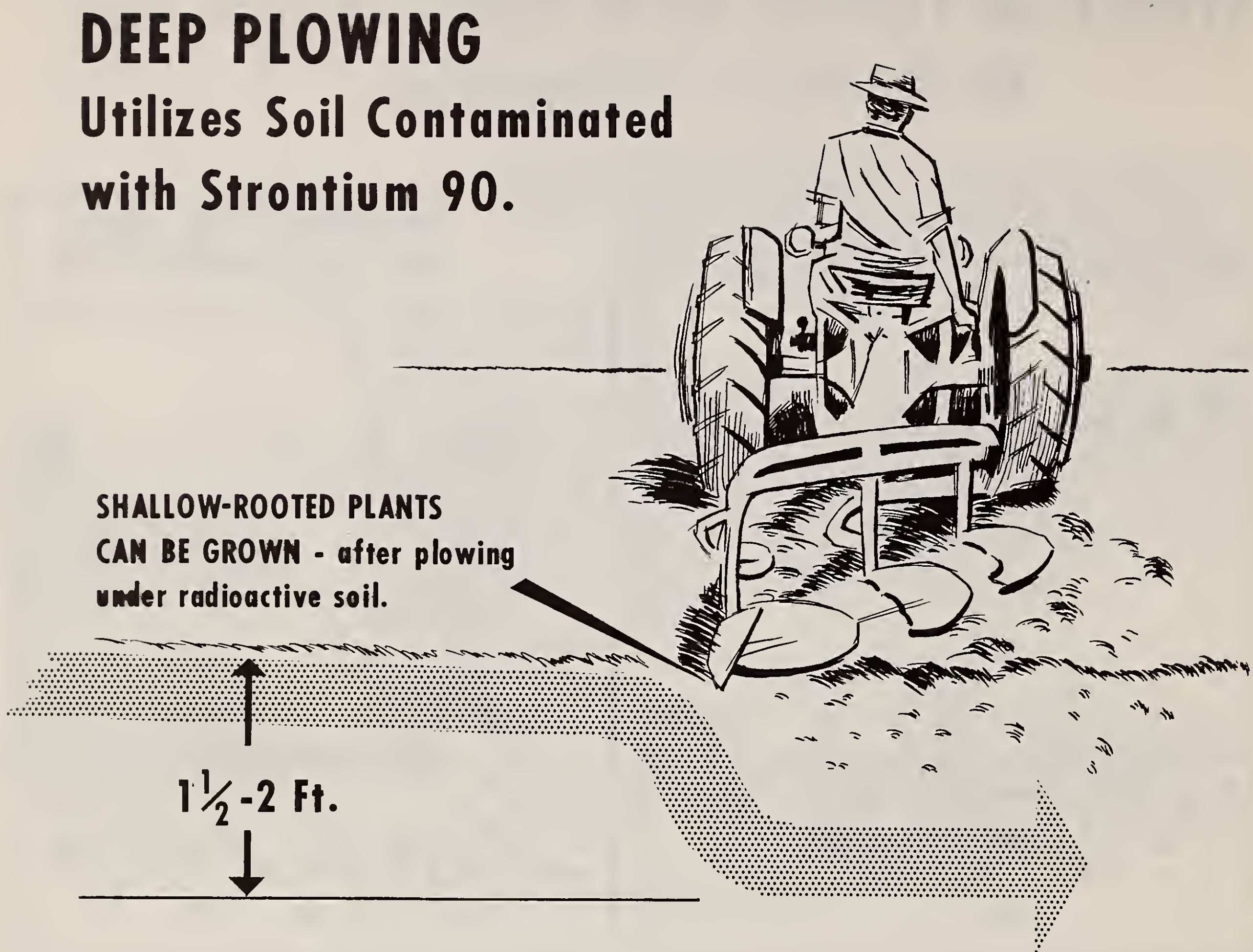
BN-13663

Figure 62.

Welfare, and the U. S. Department of Agriculture. Ion-exchange resins have been used successfully on a laboratory scale for the removal of strontium from milk. Efforts are now being made to adapt the laboratory findings to a pilot plant scale developing a standby process for commercial use in case of a national emergency.

Summary

In short, we find that in the event of attack with nuclear weapons, the hazards of radioactive fallout to agriculture would be serious. But there are practical methods of protection. Even in areas of heavy radioactive fallout contamination, proper shelters for sufficient periods of time can significantly reduce the damages of external radiation to man and his animals. The long-term hazard of internal radiation is less acute but does present a chronic problem of major concern. Through the knowledge being gained by research, we could expect to reduce this hazard by the proper use of the land and its products that provide the Nation's food supply.



BN-13664

Figure 63.

SOIL AND PLANT RELATIONSHIPS OF FISSION PRODUCTS[1]

The fission products contained in fallout particles enter the food chain of man primarily through plants and soils. Some particles are deposited initially on the plants, the remainder on the soil. It is proposed to discuss here mechanisms of intake of fission products by plants, reactions with soils, and land reclamation and decontamination measures.

A fraction of the particles deposited on food crops will be ingested by animals and humans if surface decontamination measures are not employed. Rain and wind

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1/ Compiled from statements prepared by L. T. Alexander, Soil Conservation Service, and R. G. Menzel, Agricultural Research Service, U. S. Department of Agriculture; and R. F. Reitemeier, U. S. Atomic Energy Commission and U. S. Department of Agriculture, for the Special Subcommittee on Radiation of the Joint Committee on Atomic Energy (United States Congress).

will move some of the particles from plant to soil. The extent of this movement will depend on the shape of the plant and the characteristics of the plant surfaces. Actually, the meteorological conditions occurring during the fallout affect the initial distribution of particles between plant and soil. Fallout during a moderate or heavy rain, for example, will be expected to be deposited on the soil to a greater extent than is dry fallout. The particles remaining on the plants are subject to dissolving in water, to a degree governed by the solubility characteristics of the particles, such as size and chemical composition, and the weather conditions occurring after deposition. Light rains, mist, fog, and dew increase the opportunity for this dissolving action. Some of the fission products made soluble by this action are absorbed into the plant, and a fraction of these may be translocated, that is, moved to other parts of the plant.

Subsequent rains may leach some of the absorbed radioisotopes from the plant onto the soil. These, being already in a soluble form, can participate immediately in the reactions with the soil. Those isotopes in particles deposited on the soil must first be liberated by solution of the particles, by water, acids, or exchange reactions, which involve the replacement of atoms held on soil particles. These fission products are then free, to varying degrees, to move through the soil, and to enter plant roots and be transported to other plant parts.

Some of our present knowledge has been obtained under actual fallout situations, the rest with completely soluble sources of radioisotopes. In the latter case, it is presumed that maximal biological availability of the isotope is manifested. Many results of experiments and observations on soils and plants at current fallout levels should be applicable to problems involving much higher levels, and conversely, results obtained with tracer applications; that is, much higher levels are applicable to the present conditions.

Foliar Absorption

The extent of absorption of a radioisotope by aboveground parts of plants is usually determined by spraying or painting a particular part, or the entire aboveground portion, with a solution containing a known amount of the isotope, and after washing or skinning, measuring the residual amount of radioactivity by Geiger counting or radioautography. Translocation of the isotope following absorption is detected in a similar manner, by treating only one plant part and later measuring the radioactivity in various other parts. Moderate absorption of isotopes of strontium, barium, ruthenium, and rubidium by the foliage of bean, beet, and tomato plants has been demonstrated. The translocation of the absorbed strontium to other parts, however, was slight, and negligible in the direction of the roots. Absorption of radiostrontium into tomato fruits from applications painted on their surfaces also occurred, as shown by radioautographs. The moderate leaching of root-absorbed strontium 90 from leaves by water sprays also has been established.

Following applications of solutions containing strontium 90, ruthenium 106, cesium 137, and cerium 144, to some leaves of sunflower and kidney bean plants,

the movement of cesium to the other leaves and other aboveground parts was 100 times as great as that of the other isotopes. Radiostrontium sprayed on the foliage of wheat, potato, bean, cabbage, sugar beet, and swede (a fodder beet) plants moved to untreated parts to only a limited extent, while radiocesium moved to all parts of the plant.

Floral Contamination

The spraying of radiostrontium on immature heads of wheat effected a much higher strontium content of the grain than did spraying of plants before emergency of the heads. The relatively high strontium 90 content of wheat and rice kernels during the past several years resulting from nuclear weapons testing is attributed to this floral contamination mechanism.

Plant-Base Absorption

The relatively high strontium 90 content of the foliage of permanent grass pastures in the United Kingdom has not been explainable by soil uptake or foliar absorption. The concentration in the grass of some pastures appears to be ten times as high as would be expected by way of the soil. A further mechanism, called plant-base absorption, has been proposed to explain this situation. Established grass pastures in humid climates develop a root mat consisting of upper roots, the basal portion of the stems, and other organic matter. This mat lies just above the soil surface.

According to the proposed theory, it intercepts strontium 90 washed from the surfaces of the grass leaves by rain, and detains it long enough for a considerable fraction to be absorbed into the roots or stem, and transported into the leaves. Soil reactions, which would reduce the availability of strontium to roots, as adsorption (attachment to surfaces), fixation (binding in nonexchangeable form), and dilution with soil calcium, are thereby avoided. A consequence, in addition to the increased efficiency of uptake by the grass, is that the strontium 90 content of the plant depends primarily on the current rate of deposition of fallout and not on the cumulative amount of strontium 90 in the soil; this applies also to foliar absorption when it is the predominant intake pathway. This mechanism would be expected to be less important in other areas. Pastures in the United States, for instance, are replanted relatively frequently, and the vegetation often is a legume or a grass and legume mixture.

Soil-Plant Factors

The customary problem in soil fertility is the increase of uptake of chemical elements by plants. The main goal of research on radioactive contaminants, however,

is the reduction of uptake of elements. The absorption of a radioisotope from soil by plant roots requires the simultaneous occurrence of three conditions. The isotope must be in the active root zone of the plant, its binding to soil particles must not be too tight, and the plant must have a mechanism for the absorption of the particular element. Most fission products of greatest importance in the food chain, for example strontium, cesium, barium, ruthenium, and rare earths, occur in soils and plants as cations, positively charged atoms. They become attached to soil particles, to varying degrees, by such chemical reactions as adsorption, cation exchange (replacement of one cation by another), and chemical precipitation. Of this group of elements, strontium is consistently found to be absorbed the most. The others are absorbed only to a relatively slight extent.

Strontium behaves similarly to the chemically related nutrient element and important exchangeable cation, calcium. Where both the exchangeable strontium and calcium are uniformly distributed through the entire root zone, as in most pot experiments, the ratio of the two elements in the shoots is approximately the same as on the exchange complex (colloidal clay plus organic matter) of the soil, that is, discrimination between the two is slight. In the field, however, the strontium 90 and calcium seldom are uniformly distributed in the root zone of any crop. Further, the root habits of crops vary with soil conditions. Where the strontium 90 is located near the soil surface, shallow-rooted crops, as many grasses, will have a higher strontium to calcium ratio than deep-rooted crops. Where it has been moved to a lower depth, as by plowing, the ratio in shallow-rooted crops will be reduced.

Dilution of the strontium 90 by natural or applied available calcium, that is, in a form which can supply plants, often reduces the strontium 90 content of the crop. In this country differences among soils are more striking than effects of liming of a particular acid soil. The range of natural exchangeable calcium levels is wide, while even in very acid soils the exchangeable calcium level usually can be raised only several fold by lime applications. Additions of lime in excess of the cation exchange capacity (ability of a soil to hold exchangeable cations) are of no benefit. It is currently recommended that lime be applied only in amounts expected to provide better crops.

Fertilizer applications have diverse effects on the uptake of fission products from soils. Nitrogen fertilizers were found to increase the strontium 90, cesium 137, and cerium 144 content of oat plants, but phosphorus fertilizer decreased the cesium 137 uptake. Potassium additions have been reported to reduce the uptake of radiostrontium by radish plants and wheat plants and the uptake of cesium 137 by wheat and pea plants. These effects of potassium are in accordance with the depressing effect of excessive potassium on the uptake of calcium and with the chemical similarity of potassium and cesium.

Cesium and potassium differ materially from strontium and calcium in their chemical behavior in the soil. In addition to the categories of available and mineral lattice ions attributed to strontium and calcium in the soil, there is a third condition or state that falls between these two so far as the plants are concerned. In this condition the cesium and potassium ions are neither readily available to plants nor are they completely inaccessible to them. Depending on the level of potassium in the exchangeable form, some of these ions may become available to the plant. In soils

containing certain types of silt or clay particles, the potassium may become a part of a mineral in which it is unavailable to plants and cannot be leached from the soil. While we do not know as much as we would like to know about the behavior of cesium in soils, it seems reasonable that it would be more tightly held than the potassium. And this does indeed seem to be the case. Plants take up but little cesium from the soil and it is difficult to remove it from the soil by replacement with another ion.

It would appear then that cesium 137 falling on the soil in amounts equal to the strontium 90 will be a lesser constituent in the plants that are used by man and animals for food and feed.

The rare earths and plutonium are so tightly held by soil and so little taken up by plants that they will be of slight or no concern to man or animals by entry through roots. It has been shown that some plants — particularly trees — can take up and differentiate between some of the rare earths. However, the total amounts involved are so small that they are of no importance in the fallout problem.

Since soil movement is one of the main processes by which the land is formed, and man accelerates this movement by cultivating and overgrazing the soil, it is inevitable that part of the fallout deposited in many areas will be moved into lower lying positions. These soils formed at the foot of slopes and in stream bottoms may accumulate larger amounts of fission products than fell on them directly. In the case of thin sheet erosion and subsequent deposition in a lower lying position, the concentration could be many times as high as the area has received on the average through direct fallout. As pointed out above, the elements with which we are concerned are rather tightly held by the soil, and where the soil goes they go. For the same reason, water that has moved through the soil will have had most of its long-lived radioactive contamination removed. On the other hand, fission products in water might move through relatively large underground channels in rocks for considerable distances before they were adsorbed on the channel walls. Inland lakes that have no exits must accumulate fission products to the extent that these are carried in the water and sediments of the entering streams.

While the downward movement of long half-life fission products that we are discussing is slow, there are differences in rate of movement that reflect the capacity of the soil to hold such elements in the ionic state. Sandy soils, for example, will generally have deeper penetration of strontium 90 than will the finer textured silt loams and clays. Mechanisms for penetration of fallout into soil below the surface few inches are the earth mixing due to earthworms and the development of large cracks in some soils during dry weather. When the rains come, surface soil material flows into the cracks and carries the surface deposited strontium or cesium downward. In most of our soils that have not been cultivated since 1953, the bulk of the strontium 90 — say 75 percent — is found in the upper 4 inches of soil.

The possibility of a mechanism for the nonexchangeable fixation of strontium 90 also has been under investigation. In order to be of appreciable benefit in the reduction of uptake, most of the strontium eventually would have to be fixed. On the other hand, even a relatively slow rate of fixation might be important, because of the 28 year half-life of strontium 90. Certain experiments have shown no reduction of availability of strontium to plants with time. Intensive extraction of California soils with

concentrated calcium chloride and ammonium acetate solutions removed all but several percent of radiostrontium applications, but this does not preclude the possibility of long-time fixation effects. Salt extractions of soils containing strontium 90 from fallout or applications of strontium 89 have shown a greater retention of radiostrontium by southeastern soils than by Ohio soils. Efforts to determine the existence of slow fixation reactions and of more rapid chemical precipitation reactions by the addition of chemical compounds are continuing.

Entry into Biological Processes

When fallout lodges directly on plants that are eaten by man and beast, all of the radioactive elements which are present in it may be of concern. Strontium 90 and cesium 137 can be metabolized by the plant and become a part of it even though not coming through the roots. The extent to which the rare earths and plutonium would remain on the plant material and be ingested by man and animals is not well known at the present time. It is believed that they are of less concern than strontium 90.

Alfalfa grown on two very sand soils in Illinois derives its calcium from high calcium subsurface horizons rather than from the plowed layer. In these cases, the uptake of strontium 90 has been very small in comparison to vegetation that obtains its calcium largely from the plow depth, where the strontium 90 occurs. The uptake of strontium 90 by shallow-rooted plants is not so erratic as for the deep-rooted plants such as alfalfa and sweet clover. These deep-rooted plants may be getting the bulk of their calcium near the surface, if growing on an acid soil that has been limed. On the other hand, as mentioned above, the alfalfa may be drawing its calcium from a deep horizon and consequently getting little strontium 90 from the deposition of fallout on the surface. Soils having abundant calcium in the soil zone containing the fallout will produce vegetation of lower strontium 90 content than comparable soils with low calcium levels.

Cesium 137 seems to be taken up more rapidly by plants from solution cultures than from soils. Apparently, the cesium ion is so firmly held by the soil surfaces that it is not readily available to plants. Likewise, the rare earths and plutonium are little taken up by plants from soils; hence these elements become of interest only to the extent that they are deposited directly on foodstuffs or in water supplies.

Soil to plant discrimination factors have been of considerable interest to those working with fission products that get into the food chain. Evidence for a discrimination against the uptake of strontium relative to calcium is conflicting. Some data based on tracer experiments have indicated that there might be a 2 to 1 factor against strontium uptake.

Menzel and Heald made two studies designed to measure discrimination between stable strontium and calcium, one in the greenhouse and one in the field. In the greenhouse experiment with 10 crops on 4 soils, the average discrimination factor for stable strontium and calcium between soil and plant was 0.7. Under field conditions at 93 sites in 11 states no discrimination, on the average, was found between the ratio of calcium and strontium in alfalfa and wheat and the ratio in the exchangeable form in the soils on which they were grown. There may be no single answer to

the problem, but it seems that one should not count on a large discrimination factor for strontium.

It should be emphasized that discrimination factors, where they exist, are strictly applicable only to equilibrium conditions. Probably none of our soil root zones has been brought into equilibrium with the recently added fission products. Thus, it is difficult at this time to make calculations based on uptake found under field conditions. Variations are due to unequal distribution of the fission products and exchangeable calcium in the soil, and to uncertainties as to what constitutes the root zone of plants.

Reclaiming Contaminated Soil

Decontamination of soils usually would be necessary only for the removal of strontium 90. Other biologically significant fission products either are taken up from soils by plants in much smaller amounts or have such short lives that decontamination is not necessary. In zones of heavy fallout, stringent decontamination measures will be necessary in order to reduce the strontium 90 content of the soil to a level acceptable for production of vegetables and milk. (These products absorb a greater percentage of the available strontium 90 than do others.) For production of other crops, or in zones of lighter fallout, practices that reduce the uptake of strontium 90 to a lesser degree may be sufficient. Obviously, heavily contaminated lands (over 1,000 r/hr at H + 1) should be placed in cultivation only when absolutely necessary.

Decontamination by Removal of Ground Cover

Decontamination by the removal of ground cover is effective when the existing cover is thick enough. The cover provided by sod or by a mulch consisting of 2 tons of oat straw per acre is practically complete. More than 90 percent of the fallout on sod or mulch may be removed by removing the sod or raking off the straw. Less dense cover, of course, would provide less effective removal. Standing crops usually provide less complete groundcover, especially when young, and their harvest may remove only a small fraction of the fallout.

Contaminated crops could be disposed of by harvesting and baling to reduce their bulk. The bales must be stored where they will not contaminate other foods. The workers should wear respirators to avoid breathing the dust created by these operations. Clothing should be kept as clean as possible. Thorough washing of the hands and face before eating are necessary.

Decontamination by Removal of Surface Soil

The removal of surface soil is one of the most effective methods of decontamination, but it is expensive and — with the procedures developed at this time — not suitable for large acreages. It might be useful if small clean areas are needed to produce food for survival.

The effectiveness of decontaminating surface soil by scraping ranges from partly successful for rough land to highly successful for smooth land. Rough, freshly plowed surfaces are difficult to decontaminate. Scraping off 2 inches of soil with a road grader may remove over 99 percent of the fallout from smooth soil, and only 60 percent from rough soil. Rough soil surfaces may be decontaminated more completely by scraping off more soil. Just as in harvesting, precautions against breathing dust and for cleanliness are necessary.

The safe disposal of contaminated surface soil after removal is a serious problem. For large volumes, the only practical places for disposal appear to be pits in center of small fields or regularly spaced ditches across fields. The pits or ditches would have to be protected from erosion and could not be used for crop production.

Other Methods of Decontaminating Soil

Several additional methods of decontaminating soils do not appear to be practical on a field scale. Among these are leaching and cropping soils to remove strontium 90. Leaching would require extremely large amounts of water and calcium salts or acids. In addition to removing strontium 90, plant nutrients would be leached out of the root zone and would have to be replaced. Cropping, even with those crops known to take up large amounts of calcium and strontium, would require more than 40 successive crops to achieve 90 percent decontamination.

Reducing Strontium 90 Uptake with Soil Amendments

Addition of fertilizers or organic matter in practical amounts usually reduces uptake of strontium 90 by less than half. Combinations of soil amendments and tillage practices may reduce uptake more than any single amendment would. The best use of soil amendments for reducing strontium 90 uptake is often the same as their best for maximum crop production.

The plant's need for calcium leads to the absorption of the similar element strontium. In soils low in exchangeable calcium, more strontium 90 will be taken up by the plant. By liming acid soils, more calcium is made available to the plant and less strontium 90 will be absorbed. It is useful on highly acid soils on which liming would be normally beneficial for other reasons. (Gypsum would be most useful on soils containing large quantities of exchangeable sodium, which would normally need gypsum regardless of the strontium 90 hazard.) However, at best the application of lime reduces the strontium uptake to about one-half the uptake if the soil were not treated.

Potassium fertilization at the rate of several hundred pounds per acre can also reduce the uptake of strontium 90. However, the calcium uptake by the plants is also reduced by this practice. Crop residues and manure applied at the rate of 20 tons per acre have reduced the uptake of strontium 90 by one-third.

Reclaiming Soil by Deep Plowing

Decontamination by deep plowing would be aimed at turning the contaminated surface soil under to a depth of 18 inches or more — or below the root zone of the

plants that are to be grown. Deep plowing might reduce the uptake of strontium 90 by about one-third compared to that without treatment in shallow-rooted crops such as grasses and many vegetables. It will be most effective when the freshly exposed surface soil has a high supply of calcium either naturally or by addition of lime or gypsum. However, before the method is used, careful evaluation should be made of the situation in the area and of the alternatives. Once strontium 90 has been plowed under, future removal is extremely difficult. Also, the productivity of some soils may be drastically reduced by this treatment.

Questions

1. Assume megaton fission bombs were exploded near the ground in May 1960 at Chicago, Detroit, Cleveland, and Sault Ste. Marie, with prevailing northwest winds. Consider that crop contamination comes from two sources, uptake from the soil and direct fallout from the atmosphere. Which will be the major source for:

   a. Iodine 131 in New York milk,

   b. Strontium 90 in North Carolina snap beans in 1960,

   c. Strontium 90 in Virginia peanuts in 1970,

   d. Strontium 90 in North Dakota wheat in 1962, and

   e. Strontium 90 in Ohio wheat in 1962?

2. Cesium 137 is considered to be less hazardous to man than strontium 90 because:

   a. Cesium 137 has a much shorter biological half-life,

   b. The amount of cesium 137 produced by nuclear explosion is much less than the amount of strontium 90, or

   c. Cesium 137 emits primarily beta radiation while strontium 90 emits primarily gamma radiation.

3. Farmland contaminated by fallout with strontium 90 can be reclaimed most efficiently by:

   a. Leaching the strontium below the root zone,
   b. Removal of the contaminated crops or cover, or
   c. Removal of the surface soil.

4. The addition of lime may reduce the uptake of strontium by plants by (2/3, 1/2, 1/3, 1/4). Other soil amendments usually (are, are not) as effective.

UPTAKE AND RETENTION OF FISSION PRODUCTS IN ANIMALS AND MAN[1/]

The relative hazard of disseminated radioactive materials will be governed by the amount released into the environment, physical half-life, efficiency of transfer through the food chain to the human diet, degree of absorption by the body, and length of time retained in the body. By these criteria, the radioisotopes from fallout of greatest concern are those of iodine, barium, strontium, cesium, and carbon. The fissionable materials (plutonium), as well as the rare earths are only slightly absorbed from the gastrointestinal tract of man and animals and do not, therefore, contribute importantly to the potential hazard.

In the period immediately following a nuclear incident, radiation exposure may result from sources external to man and animals; in this instance the relatively short-lived gamma emitters would be of most significance. In the period shortly after the deposition of fallout from the atmosphere a substantial fraction of any ingested radiocontaminants would originate in fallout deposited directly on edible vegetation. For animals this would primarily be forage grasses and legumes, and for man, vegetables. With the passage of time, and with the discarding of directly contaminated food, surface contamination would become of lesser importance. Also, as time went on there would be a change in the composition of the radiocontaminants; at early times I^{131}, Ba^{140}, and to a lesser extent Sr^{89} would predominate, whereas later on Sr^{90} and Cs^{137} would become the predominant radiocontaminants.

Iodine 131: For a period of days following a heavy deposition of fresh fallout, I^{131} with a half-life of about 8 days, may be of importance from the indirect contamination of vegetation. After ingestion, iodine is rapidly absorbed from the gastrointestinal tract, collected in the thyroid gland, and secreted into milk and eggs. From 5 to 10 percent of I^{131} ingested from deposition on herbage by the dairy cow appears in the milk produced, whereas values to 20-50 percent have been reported for the goat and sheep. In the cow, the radioiodine appears in the milk at about 30 minutes after ingestion and decreases with a half-period of about 1-1/2 days for the first few days and then with a half-period of about 3 days. There are considerable variations in amounts secreted into milk depending upon seasonal variations, feeding practices, stage of lactation, and status of the thyroid gland. In limited studies, about 0.01 percent and 0.26 percent of I^{131} ingested by the cow were found in butter and buttermilk, respectively.

With laying hens, about 8 percent of the daily ingested I^{131} was found in each egg with most of the radionuclide being present in the yolk.

Barium 140: This radionuclide has a half-life of about 13 days and is metabolized much like calcium and strontium, being deposited in the skeleton. About 5 percent of the amount ingested is absorbed by the cow and about 0.4 percent secreted into the milk. Because of the short half-life and the comparatively poor absorption, the dose contribution of Ba^{140} to man or animals is small compared to that from other radionuclides.

Strontium 90: At early times after release of nuclear debris Sr^{89} would constitute the major fraction of the radionuclides of strontium; because of its 54 days

1/ Prepared by C. L. Comar, Department of Physical Biology, New York State Veterinary College, Cornell University.

half-life, however, its importance would decrease with time so that Sr^{90} (half-life, 28 years) would become the primary long-term hazard. The behavior described for strontium in general also holds for Sr^{89} and Sr^{90}.

Strontium is readily absorbed from the gastrointestinal tract, but somewhat less efficiently than is calcium, and a large fraction of that absorbed is accumulated in the mineral portion of bones, similarly to calcium. This deposition in the bone occurs partly by an exchange replacement of calcium ions located in the surfaces of the mineral crystals and partly by bone growth. The concentration of strontium 90 in the bone relative to calcium is not uniform unless the ratio of strontium 90 to calcium in the food has remained reasonably constant during the entire period of development of the skeleton. At any one time, the skeletal deposition of currently ingested strontium occurs preponderantly at sites of active bone growth and reforming bone tissue. The radiation at these sites from strontium 90 and from its daughter by decay, yttrium 90, is a potential cause of bone cancer and damage to the blood-forming tissues. The likelihood of this injury in general would increase with the skeletal concentration of strontium 90, and with the length of its retention in the human body is many years depending upon the particular location in the bone. Because the radiological half-life is 28 years, the main reduction in strontium 90 radioactivity during the period of residence in the body results from the process of elimination of the strontium atoms from the body.

On a typical farm ratio dairy cows have been found to secrete about 0.08 percent of the ingested Sr^{90} per liter of milk; goats, primarily because of body size, secreted much more, about 1.4 percent of ingested Sr^{90} per liter of milk.

Although strontium is closely similar to calcium in behavior, it is moved somewhat more slowly than is calcium by metabolic processes and across membranes in animals and man. The magnitude of this discrimination against strontium may be small in any one metabolic process, but by a succession of such processes, each one magnifying the preceding discrimination by a small factor, substantial discrimination between the two elements ultimately may be effected.

In essence then the movement of strontium radionuclides from soil to man is interrelated and, to some extent, governed by the simultaneous movement of calcium. In practically all steps of the food chain from vegetation to human bone, calcium is preferentially utilized relative to strontium. The differential behavior of strontium and calcium has been expressed as the Strontium-Calcium Observed Ratio (OR) and defined as follows:

$$OR_{\text{sample/precursor}} = \frac{\text{Sr/Ca of sample}}{\text{Sr/Ca of precursor}}$$

$OR_{\text{body/diet}}$ values for laboratory animals, domestic animals, and man under usual dietary conditions range from 0.18 to 0.35 with values mostly falling around 0.25; there is some evidence that OR values for the very young may be slightly higher than for the adult. The $OR_{\text{milk/diet}}$ for the goat, cow, and woman appears to range from 0.09 to 0.16 with most values falling close to 0.1. This discrimination against strontium in the lactation process is of practical importance and under steady-state conditions would cause milk to be the least contaminated of all natural sources of

food calcium. Were it not for this differential metabolism the Sr^{90} content of the U. S. population would be about five times higher than at present. In a recent study with laying hens, it was shown that the $OR_{egg\ white/diet}$ was greater than 1, actually 1.6.

The use of Observed Ratios permits: (a) Prediction of total body burdens from dietary values; (b) prediction of total diet values from tissue or excretion measurements; (c) prediction of maximum Sr^{90}/calcium ratios of any single mineral deposit in the body from measurements on diet.

The appropriate Observed Ratios can be combined mathematically to estimate the overall discrimination between strontium and calcium in the vegetation and in human bone. To be valid, these calculations must be based on reasonable assumptions concerning the fractions of the calcium intake derived from various sources, for example, cow's milk, vegetables, and the mother's body. For new born infants, the predicted overall discrimination (expressed as $OR_{body \neq vegetation}$) has been estimated to range from a minimum value of 0.10 to a maximum value of 0.045. For 6-month old children, the estimated range is from a minimum discrimination of 0.13 to a maximum of 0.041. For children over 6 months of age and adults, the estimated minimum discrimination value is 0.20 and the maximum 0.09. Expressed in another way, this means that at equilibrium the strontium-calcium ratio in bones of young infants would be from 3 to 12 percent of that in vegetation, with values of 8 to 16 percent in the bones of persons over 6 months of age. It is also pointed out that although milk is our primary source of calcium, the discrimination against strontium relative to calcium in passage from the feed of the cow to its milk tends to reduce the importance of milk as a source of strontium 90. While dairy products furnish some 80 percent of our dietary calcium, they may supply somewhat less than 40 percent of the total strontium 90 intake when steady-state conditions are established. Attention also should be given to contaminated water supplies as a possible source of strontium 90 although these do not appear highly important under present conditions.

It is apparent, therefore, that the metabolic processes in humans and animals are favorable to a substantial reduction in the level of strontium 90 in man, as compared to the level of contamination of the vegetation in the food chain and of the soil on which it is grown.

Cesium 137: Radiocesium is efficiently absorbed from the gastrointestinal tract, accumulates in muscle tissue and is secreted into milk; it may, therefore, be an important contaminant of milk and meat. Cesium is similar to potassium in physiological behavior but is not governed by potassium metabolism in the same way that strontium is governed by calcium metabolism. Cesium is rapidly removed from the body; typical biological half-times of removal in days are: mouse - 1.2, rate - 6.5, monkey - 19, dog - 25, man - 110, goat - 2, and cow - 20.

It is estimated that 6 to 10 percent of ingested radiocesium appears in the milk of the dairy cow and goat.

Other radionuclides: Attention has been given to carbon 14, half-life about 5,600 years, since this radionuclide may contribute to long-term genetic effects. In regard

to food contamination it is pointed out that the specific activity (C^{14}/total carbon) in the food chain should probably lag by about a year that of the carbon used by plants for photosynthesis. There would appear to be little opportunity for accumulation or discrimination against carbon 14 in the food chain. The major problem is then one of measurement of the specific activity of C^{14} in the atmosphere and estimation of possible genetic effects; the latter is no mean problem.

Induced radioactivities (e.g., Zn^{65}, Co^{60}, $Fe^{55,59}$) appear not to be important so far as terrestrial contamination is concerned; they may be of significance in contamination of fisheries products.

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PART III

AGRICULTURAL USES OF ATOMIC ENERGY[1/]

Atomic energy is providing the United States with an unexpected and a very welcome aid to research efforts — it is giving new techniques to scientific studies and new thoughts on old problems. The future possibilities of its uses appear to be almost unlimited.

In the course of developing new ideas or findings, there are always some who say, "It won't work," or "It can't be done." In the early days of the automobile, electricity, telegraph, telephone, radio, and television, some individuals looked on these new gadgets and services with skepticism and amusement. Today, however, these developments are taken for granted and when the switch is flipped the lights or a particular electrical appliance, or what have you, will immediately provide the desired service.

The radioisotope, like the statements on the life-saving qualities of the filter cigarette, has found its way into almost every nook and cranny of our scientific community. We are becoming more familiar with the uses of atomic energy and are using it more and more to help find answers to everyday problems. Radioisotope techniques add to the precision and reliability of many measurements that are important to American agriculture. The radioisotope, however, does not replace nor make obsolete current research methods and procedures but rather supplements them as a very useful new tool. Its use is enabling agricultural scientists to unlock vast storehouses of knowledge about soils, plants, insects, and animals.

It is extremely doubtful that atomic energy or radioisotopes will ever be used directly by farmers to increase crop yields. That is, it is doubtful that the use of radioactive materials such as fertilizer, insecticide, or animal feed will ever help the farmer. However, the knowledge that the scientist gains in how plants, animals, and insects grow and the various phenomena of nature will be the greatest returns to agriculture from atomic research.

Research in this field is in its infancy with much of the work still in the experimental stage. At times, there may be premature reporting of certain activities to the public. Under these conditions, the public may gain the impression that the reported experiments are accomplished facts or that certain accomplishments already have commercial application.

In considering the role of research in the future of agriculture — and our society as a whole — the kind of agriculture wanted must be decided. First, an agriculture that will provide the high-quality food and fiber needed for the healthful, abundant

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1/ Prepared by Frank A. Todd, Office of Administrator, Agricultural Research Service, U. S. Department of Agriculture.

life of all our people is wanted — and, second, an efficient and profitable agriculture that will offer farmers and their families a satisfactory way of life.

The fact that there are surpluses of foods in this country does not lessen the need for continued development of better means of protecting crops and livestock from diseases and parasites. On the contrary, such development would permit the same quantity of foodstuff to be raised with less effort on the part of the farmer. There is no point in the farmer spending his time growing crops only to see them spoiled or attacked by disease.

Plant Nutrition

The radioactive tracer technique has already made possible significant advances in the science of plant nutrition. There have been learned, for example, the phosphorus needs of various plants at different stages of growth and the efficiency of different phosphates.

Radioactive tracers are showing how conventional fertilizers can be used more efficiently and economically. American farmers are spending more than a billion dollars a year for commercial fertilizers. Atomic research has found ways to get greater returns in crop yields from this money.

Sometime ago scientists in California, in their work on the control of insect pests and plant diseases, found that application of certain fertilizers to dormant trees and to the foliage of trees improved growth the next year.

More recently workers in Michigan, after a severe winter, sprayed dormant trees with fertilizer, especially the isolated areas of the tree that appeared to have been injured from the cold weather. The results were encouraging with the tree regenerating and recovering. This was repeated again in midwinter and at below-freezing temperature using radioactive elements (phosphorus and potassium). Within 24 to 48 hours these materials were found in vertical branches 18 inches to 2 feet above the point of application.

This all leads to the finding of the usefulness of foliage-feeding of plants. Some farmers are now foliage-feeding their trees and some crops and are finding it helpful. The combination of insecticides and fertilizer is a common way of application. In some cases, instead of limestone, bonemeal, raw rock phosphate, etc., there are now water soluble fertilizers containing 40 percent nitrogen that are applied as sprays. The leaf has been found to be a very efficient organ of absorption and these materials enter easily. Materials will enter the leaf at both the upper and lower surfaces. They enter the leaf day and night.

Textbooks used to tell that the leaf was covered with an impervious cuticle. Because of these findings, textbooks have had to be rewritten. Scientists claim that this is the most efficient method of applying fertilizer to plants yet discovered. About 95 percent of soluble fertilizer applied to the leaf is absorbed while only 10 percent is used if placed in the soil.

The idea of mineral elements gaining entry to the body of the plant only via the roots was a general belief until the United States workers demonstrated the spectacular results from applying fertilizers directly to the leaves of plants.

Perhaps one of the greatest potential findings in the application of radioisotopes to agriculture will come about from the development of desirable genetic changes in food materials. It has been found that irradiating seed or a growing plant greatly increases the rate of mutation. Desirable characteristics that may be produced by radiation include disease resistance, increased yield, and improved shape and size of plants. Plant breeding by conventional methods is a relatively slow, tedious, expensive process which frequently requires years, sometimes a human generation, to produce a desirable species.

Mutations occur spontaneously at various rates for different kinds of plant species. In corn, for example, the natural mutation rate is perhaps 3 mutations in 10,000 normal progeny. However, if corn is irradiated in a nuclear reactor, the rate of mutation can be increased approximately to 3-4 in 100 — which is a factor of 100. Atomic energy, therefore, has given geneticists a very important tool for the development of new plant species. It must be emphasized, however, that all mutations are not desirable. Only an extremely small percentage, if any, can be utilized and then only after much work and many trials.

Finding the best kind of radiation and the best kind of doses is still largely a matter of trial and error — various kinds of radiation at different doses must be tried. The response which one plant gives may not be repeated in a different species of plant. Effects on seed are different than those of buds. Dividing cells are more sensitive than resting cells.

The Brookhaven National Laboratory on Long Island, N. Y., has an interesting and novel setup for conducting radiation activities on plants. They have a large circular field of about 10 acres with a very powerful source of radiation in the center of it. The plants can be grown in concentric rings around that source, all the plants on one ring receiving the same amount of radiation. The farther away from the source the ring is, the lower the amount of radiation reaching the plants. The intensity of radiation falls off according to the inverse square law: All the plants that are in a ring, say, 1 meter away from the source will receive four times the dose of the plants that are 2 meters away. Originally the system was to plant the seed in this field and then keep the individual plants there throughout their entire life cycle. Those nearest the source showed serious radiation damage and many of them were killed. Those in the outer rings showed much less damage, but a large number of interesting gene mutations were obtained. The radiation source was a powerful one — 1,800 curies of cobalt 60. (The radiation from radiocobalt is gamma radiation.)

At Brookhaven work on fruit plants is still in its infancy. Many different kinds of trees, shrubs, and vines are growing in this radioactive field. As abnormal branches appear, they are cut off and grafted to normal trees. The desirable mutations are separated from the undesirable ones.

Radiations can be useful in studying and controlling plant diseases. First, radiations may be used in producing virulent strains of plant disease organisms, so that it might be known what might appear in the future and then breed resistant

varieties of crop plants and, second, in attempting to increase the number of resistant varieties by speeding up the process of mutations, compressing into a short time what would take much longer under natural conditions.

The University of Minnesota has conducted experiments using radiation to produce mutations in corn smut and many other plant disease fungi. To wait for mutation to be made by nature might require 25 to 50 years. New races of disease organisms appear naturally from time to time, and new breeds of plants must be developed that are resistant to them. These radiation experiments provide a great many mutants with varying degrees of virulence for which new resistant plants must be found.

Work at the North Carolina State College of Agriculture has resulted in the production of three varieties of peanuts — one having about a 30-percent higher yield, one resistant to common leafspot disease, and one having a shape and size better adapted to mechanized harvesting. The next step is to try to combine these three desirable characteristics into one plant.

Dr. Calvin Konzak of the Brookhaven National Laboratory is reported to have produced rust-resistant oats with a good yield. This was done in 1-1/2 years compared to the longer period required by conventional plant-breeding methods.

Scientists in Sweden using radiation techniques have developed varieties of barley with increased yield, longer straw, and adapted to drought conditions. Swedish scientists are expanding their efforts to wheat, oats, lupin (a fodder crop), soya bean, flax, and white mustard. Work on white mustard has resulted in increased yield and a 7-percent increase in oil content. This new variety has been released on the market.

Photosynthesis

Photosynthesis is the most important synthesis that occurs on earth. It is the process whereby green plants take the carbon dioxide of the air and convert it into carbohydrates, such as sugar and starch, and into other compounds, in the presence of sunlight.

Photosynthesis is the basis of all life in that animals eat plants. It is the process through which the radiant energy from the sun is stored in chemical energy of plants. In addition, practically all the power, heat, and artificial light that modern man uses comes from the handling of fuels in which energy was originally locked up by the process of photosynthesis. A conservative estimate of the annual total photosynthesis of the world would be over 300 billion tons of sugar.

Radiocarbon tracer technique is used to find out how carbon dioxide is handled once it has entered into the plant.

Fight Against Pests

Radioisotopes are proving to be exceptionally useful tools in studies that should lead to the development of better weapons for control and improved methods for

safeguarding our harvests. A recent estimate for the world losses of food caused by pests was 30 percent of the total production.

In dealing with agricultural pests, a thorough knowledge of the life cycle is needed in order to be able to work out really effective measures for control. Full and detailed knowledge of the life cycle and habits of insect and rodent pests are not easily collected. Pests, such as the wireworm, cutworm, and mole, live out of sight underground, and before tracer materials were available it was extremely difficult to follow their movements in the soil.

Radioactive tags (cobalt 60) placed on or in the insect or rodent provide an excellent means of locating their position and following their movements by means of a Geiger counter. It is possible to calibrate the meter so that the needle reading gives the depth of the pest below the soil surface.

Radioactive tags have been used on many different species of insects to gain a better understanding of when and how they attack a particular crop with the most damaging results. This can help to develop more effective and cheaper control measures.

Similar approaches have been made in tagging pests that live and move above the ground. When tagged, insects are released on farm land and it is far simpler to track their movements and whereabouts with a Geiger counter than by visual means. These insects are well camouflaged and, therefore, are difficult to detect against their natural background.

Screwworm Eradication

Of the many types of insects that infest animals and cause considerable economic damage, the screwworm fly is selected to illustrate the potential of atomic energy in agriculture. Each year the screwworm fly causes an estimated loss of many millions of dollars to the United States livestock industry, especially in the Southern States. More specifically, it has caused about $20 million annual loss to the livestock owners of the Southeastern States. It is estimated that it has cost Florida cattlemen $3.4 million a year just to treat animals infested with this insect. From June 1956 to July 1957, over 80 percent of all wounds of cattle in Florida were infested with the screwworm.

Entomologists have studied the life cycle of the male and female screwworm flies and have learned, among other things, that the female mates but once in its entire life span — and equally important — that this proclivity is not characteristic of the male fly.

Entomologists of the Agricultural Research Service at Kerrville, Texas, found that the pupae of the screwworm when exposed to the proper amount of radiation produced sterile flies. This led to the plan of using laboratory-reared sterile flies to reduce the population of screwworm infested areas and eventually to eliminate the pest. Field tests revealed that when sterile males greatly outnumbered the wild flies, eggs from most female flies did not hatch. Mass liberation of sterile flies by air at carefully timed intervals eradicated the pest from one of the Caribbean Islands.

Encouraging results were obtained in a pilot-plant operation covering 2,000 square miles in the vicinity of Orlando, Fla., in 1956-57. Plans to eliminate this insect in the entire southeastern area of the country were developed.

Facilities were designed and built, capable of producing 50,000,000 sterile screwworm flies weekly for use in the eradication program in that area covering approximately 50,000 square miles. Although this area remains under close observation, the program was highly successful in that there is little doubt but that the screwworm fly has been eradicated from this section of the country. This was accomplished in less than 2 years.

It is estimated that the total cost was in the neighborhood of about $10 million, which equals the estimated annual loss to Florida alone from this pest.

It should be stated that the irradiated flies carry no radioactivity and are not household nor picnic pests.

In the Southwest the problem is more complicated by the fact that the screwworm overwinters in Mexico and can enter this area across the border. Perhaps the development of new pesticides more effective than those now available, or perhaps even the use of the atomic energy technique, may provide the required tools with which to eliminate this pest from that part of the country.

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HANDLING RADIOACTIVE MATERIAL[1/]

Ingestion presents the greatest potential hazard in the handling of radioactive materials. Once it is inside the body, little can be done but to permit the damage to run its course. We can expect considerable intestinal irritation and, in addition, such materials as radioactive iodine will be concentrated in the thyroid gland and radioactive strontium will be concentrated in the bones. Contaminated hands or cigarettes

1/ Prepared by Robert A. Moody, Meat Inspection Division, Agricultural Research Service, U. S. Department of Agriculture.

frequently result in oral contamination. Inhalation of radioactive gases or vapors should be guarded against. Fallout inhalation presents a relatively small hazard but absorption of radioactive materials through the skin is a possibility.

External exposure is of most consequence when whole body radiation is received. Gamma rays readily penetrate the body and are the chief danger in this regard. Hands, feet, or other localized portions of the body may receive larger doses than can be permitted for whole body exposure. External beta particle damage is usually confined to the surface of the body; however, it does add to whole body exposure to a limited extent.

Protective measures for persons handling radioactive materials can be subdivided into using good procedures, having good work habits, and observing personal cleanliness. When using radioactive liquids, work on trays or protect tables with absorbent or waxed paper. Tables frequently used to handle radioactive materials can be coated with plastic materials that can be stripped off should contamination occur. Radioactive solids should be handled with tongs, or other protective devices. Ventilation should be provided, if necessary. When handling larger amounts of radioactive material, wear protective clothing, such as gloves, and coveralls. Adequate storage facilities and waste disposal should be provided. It is important to evaluate and control the dose personnel will receive. To do this, a personnel dosimeter (CD V-138) with a range of 0 to 200 milliroentgens per hour should be worn. A Geiger counter can be used to indicate the exposure rate, used for personnel monitoring, and to check for contamination. General rules governing the use of radioactive materials and radiation equipment in the Department of Agriculture are contained in the USDA Radiological Safety Handbook, July 1, 1959.

<u>The Cobalt 60 Source Set</u> (CD V-786), furnished by the Office of Civil and Defense Mobilization, is used for demonstration purposes and calibration of the CD V-700. The accuracy of this source is plus or minus 25 percent, so its use in instrument calibration is questionable if fine accuracy is desired. Only licensed personnel are permitted to use this source set. The set has a CD V-792 outer storage container. This is made of lead and is sometimes termed the "pig." The CD V-791 is the small inner true container of the sources and is also made of lead. Two padlocks are furnished for these containers and the assembled set weights 250 pounds. There are 12 individual sources which have a total initial activity of 30 millicuries. The half-life of cobalt 60 is 5.3 years. The set contains the following sources:

4 each--------------- 5 millicuries
2 each--------------- 3 millicuries
2 each--------------- 1 millicurie
4 each---------------.5 millicurie

Cobalt 60 is made by bombardment of cobalt metal with neutrons.

$$_{27}Co^{59} + n \longrightarrow {}_{27}Co^{60}$$

	RADIOACTIVE	STABLE
The cobalt 60 decays to nickel 60 with the release of a beta particle and 2 gamma rays.	Cobalt 60 5.3 years half-life	Nickel 60
	$_{27}Co^{60} \xrightarrow{\beta}$	$_{28}Ni^{60}$

The radioactive cobalt is nickel-coated, placed in a plastic capsule, and soldered. The nickel coating absorbs most of the beta activity. Each capsule is marked with a radioactive warning sign.

Handling

Use correct operating procedures. The handler and at least one student should wear a CD V-138 personnel dosimeter in an exercise in which the students do not participate but the source set is opened. In participating exercises, the handler and at least one student from each group should have dosimeters. The wearing of film badges is not required.

Protective Measures

Distance is perhaps the best protective measure. Keep as far away from the source set as possible when you open it. Especially avoid placing your body over the top of the container. Never handle sources with your hands. Always use the tongs provided for this purpose (item CD V-788). Take advantage of the inverse square law for shielding by distance; that is, two times the distance gives one-fourth the activity, etc.

Time

The dosage received is proportional to the time of exposure. One-half the exposure time will result in receiving one-half the dosage. Handle the sources as quickly as possible. Have dry runs before the class. If something goes wrong, the students will not receive undue exposure. Have calibration distances measured or source positions determined before opening the source containers. Instruments should be warmed up before students approach the source positions.

Shielding

Shielding for gamma rays is measured in terms of half thicknesses. This is because gamma rays will penetrate almost any practical gamma shield. To take advantage of the shielding provided by the source container as mentioned above, one should stand to the side and not over the top of the container when it is opened.

Precautions

Take no chances. Check the sources in and out. In addition to the potential health hazard, there will be considerable embarassment when reporting the loss of a radioactive source. One good way of handling sources is to place them in small paper cups during the exercises. This will avoid possible room contamination should there be a broken source. Check tongs for radioactivity after each exercise. Radioactivity on the tongs means a leaking source set.

New Source Sets

The sources in a new set come sealed in a paper bag. Break the bag and wipe each source with cleansing tissue, then check the cleansing tissue for activity. Check the carrying container for activity. After replacing the source set check for activity on the tongs. Every 6 months an activity check on the individual sources should be made.

Source Leakage

If room-wide activity is discovered, the room should be sealed and immediately reported to the OCDM Regional Office. Do not inhale dust-borne contamination. If there is minor source contamination, use masking tape, seal leak in container, and contact OCDM as above.

Storage

Storage is to be in locked limited access areas. Basements of Federal buildings often have an area suitable for this purpose. People are not to work in the storage room. The doors are to have a radiation warning sign and the name and address of whom to contact in case of emergency. The storage container is to be labeled with the kind and amount of activity and the licensee's name.

Shipment

Always ship CD V-786 sources inside both containers. Do not ship more than the normal number of sources inside the containers. Railway Express is the recommended method of shipment. The outer container is to have a Class D poison label attached. Shipments are to be made only to licensed personnel, and by written transfer.

Records

A record is to be made of each source use and the trainees by name. (See "Use of Radioactive Materials or Radiation Sources in USDA".) Each person who receives over 75 milliroentgens in a week should be recorded indicating his name and the actual dosage received. A record should be made of each source shipment and the disposal of sources recorded.

It is important that each licensee know the requirements of the Atomic Energy Commission for handling radioactive materials as contained under Title 10, Part 20, Code of Federal Regulations. A few of the more important requirements are as follows:

1. Report the theft or loss of radioactive material.

2. The permissible weekly dose is 100 millirems per week or 3 rems per 13 consecutive weeks. The hands or other body extremities may receive 5 times this dose or 500 millirems per week.

3. Persons under 18 years of age are limited to 10 percent of the above dose.

4. Demonstrations are to be conducted in restricted areas. A restricted area means one where access is controlled by the licensee. Sources are to be exposed only when the area is under the supervision of the licensee or his assistant.

Questions

1. The permissible weekly dose of radiation during peactime training activities is:

   a. 100 mr.
   b. 300 mr,
   c. 3 r, or
   d. 15 r.

2. If tongs are not available for handling cobalt 60 sources used in training:

   a. It will be satisfactory to handle them with a handkerchief,
   b. They should not be handled,
   c. They may be picked up with a tablespoon, or
   d. The set must be returned to OCDM.

USE OF RADIOACTIVE MATERIALS OR RADIATION SOURCES IN USDA[1/]

In October 1958 the Office of the Secretary assigned to the Agricultural Research Service the responsibility for all administrative functions on the behalf of the Secretary relating to radiological safety within the Department. To accomplish this end the Secretary established a Radiological Safety Committee responsible to the Administrator for regulations, instructions, and other measures for radiological safety function. Under the general supervision of this Committee there was also established the Radiological Safety Officer.

1/ Prepared by Merrill E. Jefferson, Radiological Safety Officer, Agricultural Research Service, U. S. Department of Agriculture.

The Radiological Safety Committee and the Radiological Safety Officer are responsible for compliance with all Federal and State Regulations regarding radioactive materials and radiation sources. Under the jurisdiction of the Committee, the Department has a broad license from the U. S. Atomic Energy Commission which includes specifically the use of the Cobalt-60 source sets of the OCDM in personnel training programs. Upon satisfactory completion of the Departmental Radiological Monitor Instructors Training Course, authorization for the procurement and use, on a loan basis, of such sources will be forwarded by the Radiological Safety Officer to the successful candidates. This authorization is in the form of a letter which will serve to obtain the OCDM source sets on a loan basis. (See accompanying exhibit.)

ARS Administrative Memorandum 124.1, dated November 4, 1958, presents in detail the functions of the Radiological Safety Committee and the Radiological Safety Officer, together with the procedures to be followed to obtain Committee approval for any work involving the use of radioactive materials or radiation equipment, other than the OCDM sources for inservice training.

To: Personnel Completing Monitors Training Course (Individual Named)

From: M. E. Jefferson, Radiological Safety Officer

Subject: License

This will advise you that you are authorized by the Departmental Committee to secure, on a loan basis, and use, for the purpose of training radiological monitors, the Cobalt-60 sealed sources prepared by OCDM as Models CD V-786 or CD V-784 under U. S. Department of Agriculture License No. 19-915-3 (A6).

Enclosed are memoranda pertinent to radiological safety, together with a copy of the Departmental Radiological Safety Handbook. Your attention is directed to Exhibit D, RSH, personnel radiation exposure report, Form OA-22. Such reports should be submitted promptly at the conclusion of each training session unless several are given consecutively in a period of, say four weeks, in which case the individual session total may be summarized on one form. Form OA-22 is available from Central Supply through the usual channels.

In order to comply with the requirements of the AEC Licensing and of several of the States, the Committee must receive advance notice of at least two weeks when sources are to be taken from the assigned city to some other location for use. The license specifically assigns areas in which they may be used and several States require notification by the licensee (in this case the Department) of the location and movement of sources within their borders. It is our understanding that you have been advised the location of available sources. If you have problems in obtaining them, please advise this office.

Attachments: RSH
AM 108.6
AM 124.1

PRACTICAL PROBLEMS ENCOUNTERED IN PEACETIME[1/]

In October 1957, a fire occurred in the Windscale No. 1 Reactor located in Cumberland, England. Primarily, the volatile fission products (iodine 131) escaped from the exhaust stack to be deposited downwind. This accident resulted in the contamination of 200 square miles of land and this area was temporarily taken out of milk production because of excessive radioactive iodine 131 contamination of pastures.

Several other atomic reactor accidents have taken place in other countries.

Early in 1958 newspapers throughout the country reported the jettison of a part of a nuclear weapon by a military plane near Savannah, Ga. Only six persons were in the impact area, which was small. The accident did not involve nuclear fuel that reached the critical point of fission. Similarly, a nuclear-armed Air Force plane crashed in Kentucky in 1959. However, in this instance the authorities reported no resultant contamination of the area.

Since the beginning of continental weapons testing in this country, with its associated fallout, problems are posed in agriculture from time to time on the possible effects of present fallout on livestock, crops, and food products derived therefrom. Agricultural officials are confronted with such questions on occasion by livestock owners and farmers. A better understanding of atomic energy and the effects of radioactive materials, as well as their limitations under present conditions, would be helpful in investigating and discussing these inquiries. As has been pointed out, there are no specific symptoms or pathology associated with radiation. Many animal diseases can produce similar tissue changes. There are approaches, however, that should be kept in mind in conducting these peacetime investigations.

If after examination of the livestock no conclusions are reached, it is in order to collect fresh and preserved tissues for radio assays and other laboratory examinations. Suggested collections comprise thyroid glands, skin lesions, and bone tissue (rib or head of femur). It would also be in order to collect this tissue when evidence of damage from ionizing radiation is found. Any other tissue that is apparently abnormal also should be collected and preserved for examination. A 10-percent formalin solution is an adequate preservative for most tissues. Symptoms of many diseases could be confused with certain symptoms exhibited by irradiated animals but when the entire picture of irradiation toxicity is considered, few problems in the diagnosis will be likely to occur.

Suggested Five-Point Survey

Any epizoological survey in cases suspected of being due to ionizing irradiation should include:

1. Determination of amount and character of radiation present or past to which animals were exposed.

1/ Prepared by Ted Rea, Animal Disease Eradication Division, Agricultural Research Service, U. S. Department of Agriculture.

2. Physical examinations for presence of beta burns or presence of highly radioactive particles on hide.

3. Samples of feces and, if possible, bone and thyroid (other organs if facilities for analyses are not limited) for radioassay.

4. Peripheral blood samples.

5. Environmental survey, including an examination of other herds in the area to determine the presence or absence of exposure to radiation source or intensity. This should also include complete examination of animals and environment for presence of other causes of disease.

Some examples of disease investigations concerning livestock have been publicized. Owners and the press have suggested that the diseases were due to radioactive fallout. The history of one case was briefly as follows:

During the decade after World War II, Texas and the Southwest underwent severe drought conditions. During this time one cattle owner moved his cattle from Texas to Oklahoma early in the summer because of the poor pasture conditions in Texas. While these cattle were in Oklahoma, the pastures there were severely affected by drought. The following spring a cattleman decided to disperse his herd. The entire herd was moved into a market center in Texas for dispersal.

Because of the poor condition of the cattle, they were not sold. After 10 days in the market center pens, the cattle were moved to pasture in the mountains of northern New Mexico. The cattle were moved by truck to about an 8,000-foot level, then trailed to about a 9,000-foot level and released on 9,000-foot, or higher, pastures. During the movement from the 8,000-foot mountain range, the cows were calving.

Shortly after this movement rain occurred, followed by blue snow[2/], and then 40 inches of white snow. Soon after this severe snowstorm many dead birds were observed around the ranch house. Cattle were reported to have swollen noses and lips, which were reported as "smarting," and eyes and faces were also reported as being badly burned. Four days after the blue snow a prospector reported a reading of 12 on a 0.25 band of 111B scintillation counter[3/]. Background was reported as usually 7-10 on a 0.025 band. Water in the creek was radioactive, and the snow had a yellowish glow when observed under a mineralite.

About 500 cattle of the herd were penned on an 800- to 900-acre pasture, which was mostly covered with locoweed (Oxytropis lambertii) and a good mountain pasture grass. The infestation of locoweeds on this pasture was 36 plants to the square yard. The cattle were reported to have begun dying shortly after their arrival at the mountain pasture.

2/ It has been reported by some Canadian authorities that the blue snow was due to pollen from pine trees. This occurs only after an early spring growing season.

3/ Probably a lower reading than could be obtained from a luminescent dial of a man's wrist watch.

The cattle in adjoining pastures, which were raised locally, were in good physical condition and the owners reported fewer than normal deaths. About 6 months later the affected cattle were continuing to die and Atomic Energy Commission representatives and Department of Agriculture veterinarians were called to make an investigation of these livestock losses. Upon their arrival at the pastures where the cattle were grazing, they observed many of the cattle affected with two conditions. Some appeared extremely excitable and others had extremely large briskets, with edema in the throat, neck, and belly regions. Many of the cattle were affected by both conditions simultaneously.

As the cattle were being gathered for examination, one of the animals became extremely excited; it broke down two wooden gates, ran through two 4-wire heavy-gauge barbed-wire fences, and then fell in exhaustion. There were no other external lesions of great significance. Examination of blood and tissues did not show any tissue damage from irradiation; in fact, the blood counts were near normal[4/].

Although it was soon evident that the cattle losses prior to the investigations were due to poor management (possibly because of drought conditions), loco poisoning, high altitude, or brisket disease, the evidence found upon examining blood and tissues precluded the possibility of the deaths being caused by radioactive fallout. In addition, the total dose of radiation received by the cattle was probably less than is received from the face of a luminescent watch.

In connection with this investigation, Indians from a nearby Indian reservation reported similar circumstances surrounding deaths in their buffalo herd. The buffalo were reported dying from radioactive fallout which was contained in the previously reported blue snow. Upon a visit to the buffalo herd, the animals appeared normal; however, one buffalo had died the previous day. Only the skull with the skin attached, which is ordinarily used for ceremonial purposes, had not been consumed by the Indians. A few pieces of meat, which were eaten by the war chief, were reported as appearing normal. The skin and the skull were examined and the brain removed. There was a large hematoma on the brain that was collected for examination. Virulent anthrax bacteria from the specimen were isolated which readily killed guinea pigs and other laboratory animals.

Many livestock owners were sincere in their belief that radioactive fallout is causing some of their animal losses because many diseases may be confused with damage from radioactive fallout. Remember, however, as in infectious diseases, fence lines are not barriers to fallout.

In preparation for emergencies that may arise as a result of radioactive fallout, familiarity with the literature in this field is clearly desirable. The judgment of a situation is enhanced by a background of basic knowledge. Certain general information

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4/ Blood counts from cattle experimentally irradiated in the 200 r dose level showed a drastic reduction in thrombocytes and leucocytes. Other blood changes, such as increased blood-clotting time, were also seen in these experimentally exposed cattle. Deaths did not occur in the cattle irradiated at the 200 r level.

and suggestions may be helpful but specific action must be governed by circumstances, which can seldom be predicted. The following observations are offered as a general guide.

The salvage for food consumption of irradiated animals exposed to radioactive fallout in an area where the dose rate is 500 roentgens or more at 1 hour would not be acceptable. In such an area, most of the animals would exhibit symptoms and lesions described as acute irradiation syndrome before they would be accessible for slaughter. Animals with lesser exposure to radiation would be suitable for slaughter if they appeared normal on antemortem examination and on postmortem examination the carcasses were found free of gross lesions which would cause the meat to be unwholesome.

INSTRUCTION METHODS[1/]

Effective teaching is essentially the promotion of a climate favorable to learning. To reach this climate, an awareness of certain fundamentals of learning as well as methods and techniques of instruction will be of help to the trainer. How do we go about creating such a climate for learning? By understanding learning principles; by using proved and effective techniques of instruction; and by practice.

We have all heard and seen many speakers, but only a very few of these men have really changed our attitude toward a thought or subject. And to fully learn, the attitude of the student must be changed. This involves an active — rather than a passive — learning process so that the information becomes an actual part of the learner.

Here will be discussed a few of the high points of training. Although the discussion is brief, it will bring out the salient points of teaching and make it possible to train others in any chosen subject more effectively. Far more complete coverage may be found in books dealing with principles and practices of teaching. Qualified librarians can recommend good reading for further study in this field.

Nature of Learning

In answer to the question "What is learning?", we might say that it is the process of acquiring the ability to do something that the learner has not done before. Or put another way, it is the process of acquiring knowledge and habits.

1/ Prepared by James D. Lane, Meat Inspection Division, Agricultural Research Service, U. S. Department of Agriculture.

Certain accepted principles of learning are given below to serve as a guide for determining if the organization of the content, method of instruction, and methods of evaluation are in conformance with each other.

(1) Learning must begin at the level of understanding of the learner. If the teaching is above this level, the trainee will not understand and will feel antagonism toward the subject or teacher. If it is below the level, the trainee will be bored.

(2) The learner tends to associate things being learned with things already known. We learn by relating new information with related information we already have.

(3) The more the senses are used in learning, the more easily learning occurs. Visual aids and "learning by doing" are important tools to teaching.

(4) Those things that are of the greatest interest and use to us are the most easily learned.

(5) A person must be motivated to learn — the better the motivation, the more effective the learning. This often involves "selling" the subject to the student.

(6) Learning involves remembering. If a concept is really learned — so it is functional — it will be remembered. We remember approximately 10 percent of what we hear, 50 percent of what we see, and 80 percent of what we do.

Teaching Methods

The Lecture Method

The lecture method is the most widely used means of teaching, but when used exclusively, it is not always the most effective method. Efficiency of this method depends upon the ability of the learner. That is, as the educational level of the learner decreases, the effectiveness of the lecture method also decreases. This is thought to result from a lowered level of concentration and imagination in persons with a lower educational level.

The lecture method has a place in training, however, either used alone or in combination with other methods. The naration of a story for purposes of motivation is ideally suited to the lecture method. Also, it is used effectively to fill in modern developments that have occurred since the textual materials were published, as in describing a newly developed instrument. Too, it is often used to include material not covered by the text being used. An example of this would be to supply further knowledge of nuclear physics not covered in hand-out materials. A third use of the lecture method would be to introduce a new method of problem solving or to demonstrate a process or a skill. And finally the lecture method is used as a mass instructional method whereby more learners can be reached at any ont time than by any other methods.

The strong points of the lecture method can be summarized as allowing an unlimited class size; it is rapid with more material being covered; and less preparation is needed if the lecture is to be repeated often.

The weak points of this method result from the possibility of the trainees being unskilled as listeners or they may become very passive listeners. These disadvantages may be overcome to some extent by asking questions of the listeners to determine their listening and understanding ability. Another fault of the lecture method is the emphasis on content retention rather than on understanding, and this weakness is very difficult to overcome. In addition, it is hard for the lecturer to judge the proper speed to cover his material in the allotted time.

A good lecture requires careful preparation and a spirited delivery. As a beginning the attention of the class should be gained by a good introduction to the subject. Following this, ask some general questions regarding the subject to serve as a guide to determine the educational level of the class. Here we should remember once more that the learning must begin at that point in the academic work to which the trainee has progressed. Other points to insure a good lecture are:

(1) Always state the purpose within the first few minutes.

(2) Organize the content from the simple to the complex so that the listeners can follow you.

(3) Summarize the topic after each subdivision.

(4) Summarize in general at the end of the lecture.

(5) Avoid speaking in a monotone.

(6) Permit a "stand-up" recess in the middle of the period, if the lecture extends longer than 1 hour.

(7) Avoid reading a prepared script — the best lectures are delivered from outlines or brief notes.

(8) Use blackboard and other visual aids carefully with the lecture to enhance its value.

The Question and Answer Method

The question and answer method (or Socratic method) is used often with the lecture method of teaching to serve as a basis for the summary. This gives the trainees an opportunity to develop their own summaries and guides them in organizing the important materials. When the question and answer method is used by itself, it is best used with persons specificially informed on the subject. This allows trainees to hear several views on the subject and stimulates the formation of personal views by the trainees.

In preparing for this type of instruction a list of questions should be made up for the first few sessions. Also, questions from the class should be encouraged as the basis for discussion, but the instructor must keep the questions pointed at the desired objective. Questions should be asked first and this followed by a pause to allow trainees time to think and then call on some one person to answer. ''Gang'' answers disturb the class and accomplish little.

Advantages of the question and answer method are that it serves as a basis for summaries, it keeps all persons participating, and it can be used for classroom discussion.

Disadvantages are that it can degenerate into a reiteration of the textual material and if not carefully controlled by the instructor only a few of the trainees will do most of the answering.

Demonstration Method

The demonstration method is often used to illustrate the application of a particular concept or principle that has been presented in lecture form. This method is also used to supplement a laboratory exercise when the exercise is not possible and a demonstration makes lecture material more meaningful and practical. Too, demonstrations are used to orient trainees to the use of equipment. Another effective use of the demonstration method is to create a situation where observation can be made; that is, facts and data are gathered from which conclusions can be drawn or a hypothesis tested. The greatest disadvantage of this method is that the trainees would not gain the necessary experience with the instrument.

Laboratory Method

The laboratory method of training, based on John Dewey's philosophy of ''learning by doing,'' is often most effectively used following a lecture or demonstration. This moves the trainees from the realm of theory to the field of practice and is excellent for motivational purposes. Also, it develops the critical thinking ability in trainees because they are presented with an actual situation. For example: the problem must be identified (does the instrument need calibrating or is it operating properly); information must be located and used (data gathered from the instrument reading); and the solution is tested and modified if necessary (check the calibration curve with the known source and instrument of known accuracy).

Teaching Aids

Motion Pictures

Motion picures are most effectively used to introduce a unit of study and/or for motivation of trainees. They are also the ideal medium to show a far-removed event and to aid in teaching a concept when apparatus is not available. Films are equally

well adapted to review and summarize a unit, but the film should always be introduced and an explanation made of why it is being used and what the trainees are expected to gain from it. Point out specific ideas in the film. Films also are good for demonstrating an exercise but, of course, should never be used merely to fill up time.

Slides and Filmstrips

Slides and filmstrips may be more effective than movies in developing concepts because they can be held on the screen and discussed. Graphs and charts are good examples of this. As diagrams and statements can appear simultaneously, slides and filmstrips have an additional advantage. They may also be used to introduce new material, to review and summarize, or to place a great deal of information before the class at one time. They are ideal, too, in presenting accurate precision drawings or diagrams to the class and the same diagram can be used for many presentations.

Models and Mock-Ups

Models and mock-ups are used primarily when it is not practical to bring an object into the classroom or when it is desirable to show a disassembled or cutaway diagram. They are also used in explaining an apparatus and to improve the appearance of a classroom.

The opaque projector is used to show diagrams and photographs from texts not available to the trainees.

Evaluation of Teaching

Evaluation of an educational experience has three primary objectives:

(1) To estimate how much trainees have learned.

(2) To re-evaluate the concepts and generalizations on whether the course objectives have been attained.

(3) To summarize the course prepared by the instructor and to give trainees an opportunity to review the main concepts and generalizations.

Evaluation may be made by written examination, written reports, or by oral reports. The two principal types of written examinations are the essay or subjective type. Since the objective types involves making a choice — a function typical of life — and gives the broadest coverage of a course and the most reliable type of grading, it is preferred to the essay examination.

Examples of the objective type of examination are:

(1) Completion.

(2) Multiple choice answers.

(3) True and false

(4) Matching.

Reference

FCDA (Now OCDM), Interim Instructor's Guide to Radiological Defense for Monitors Course

PLOTTING FALLOUT[1/]

Evacuation, supply, and other plans essential to survival must be made prior to an atomic attack. Once an attack occurs some routes may be uncontaminated. This information must be rapidly obtained so that evacuation, may still continue. People must be alerted of forthcoming contamination so they can seek shelter, provide shelter supplies, and so forth. Although areas of major damage will be evacuated to the largest extent possible, it may be considered feasible to evacuate only a small part of the areas where fallout will reach dangerous proportions. For example, the areas of serious fallous contamination from a bomb of the kiloton range might be about 900 square miles, whereas that from the megaton size bomb might be about 10,000 square miles.

Fallout comprises a serious threat to survival greatly out of proportion to the 10 percent of the nuclear bomb energy that it represents. The contamination level is dependent upon factors that cannot be determined ahead of the attack, such as the size of the bomb, burst height, area of burst, and pattern overlap.

However, the fallout contamination area can be roughtly determined for both the kilton and megaton size weapons at any impact point after the wind pattern for the areas is known. The cloud from the kiloton bomb seldom exceeds 40,000 feet, and the fallout that will be an operational problem will be down in about 3 hours. The megaton bomb cloud will reach 80,000 feet and the fallout of concern will take up to 12 hours to descend.

Certain weather stations, known as Rawin observatories, are equipped for electronic tracking of high-altitude balloons. Wind data are determined several times daily and are available at various weather stations throughout the country in coded form. From this information, a fallout plot can be constructed. An example of the coded message is as follows:

1/ Prepared by Robert A. Moody, Meat Inspection Division, Agricultural Research Service, U. S. Department of Agriculture.

UF 35 160100Z PIT

10205
20406
40610
60914
80712

This coded information is analyzed as indicated below:

Heading

UF -- upper fallout (A code for all fallout messages)

35 -- indicates circuit code

16 -- day of the month

0100 -- 1:00 A.M. (Time indication follows the military pattern)

Z -- Zulu Time 1900Z is 2:00 P.M., EST (deduct 5 hours)

1900Z is 11:00 A.M., WST (deduct 8 hours)

PIT -- Rawin observatory that made the prediction

Body

Five series of five numbers:

The first number indicates the height of wind in 10,000 feet. There is little fallout of consequence below 10,000 feet. Kiloton bombs are of concern to 40,000 feet. Megaton bombs are of concern to 80,000 feet.

The second and third numbers represent the azimuth of the fallout line in tens of degrees from true north. True north is comparable to the grid lines of many maps.

The fourth and fifth numbers represent the range in tens of miles for a 3-hour period. Note the lower level winds are slower and more variable. The high level winds are faster and more uniform of direction. Jet winds of 30 to 50 knots are often encountered above 30,000 feet. Kiloton bomb fallout is down in 3 hours (up to 40,000 feet.) Megaton bomb fallout is down in 12 hours.

To summarize one series of numbers:

10205 means the 10,000-foot level of fallout deposits on an azimuth of 20^{o} from north and extends out to 50 miles in 3 hours. To plot the example message on a map, we would take the following steps:

1. Draw a line parallel to north through the target.
2. Construct a mileage scale card from the map scale. Extend to 150 miles.

3. Using a protractor and the mileage card, plot out the various levels on the map. The first three levels only are plotted for a KT bomb. All levels are plotted for a megaton bomb. The 60,000 and 80,000 levels only are extended for a 12-hour period.

4. To allow for the fallout cloud diameter, a circle having a map diameter of ten miles is drawn around the termination of the fallout line for the first three levels. A circle having a 20-mile diameter is drawn around the impact point and the termination of 60,000 and 80,000-foot fallout line levels.

5. A line connecting the outer perimeter of the various circles outlines the area of serious fallout contamination.

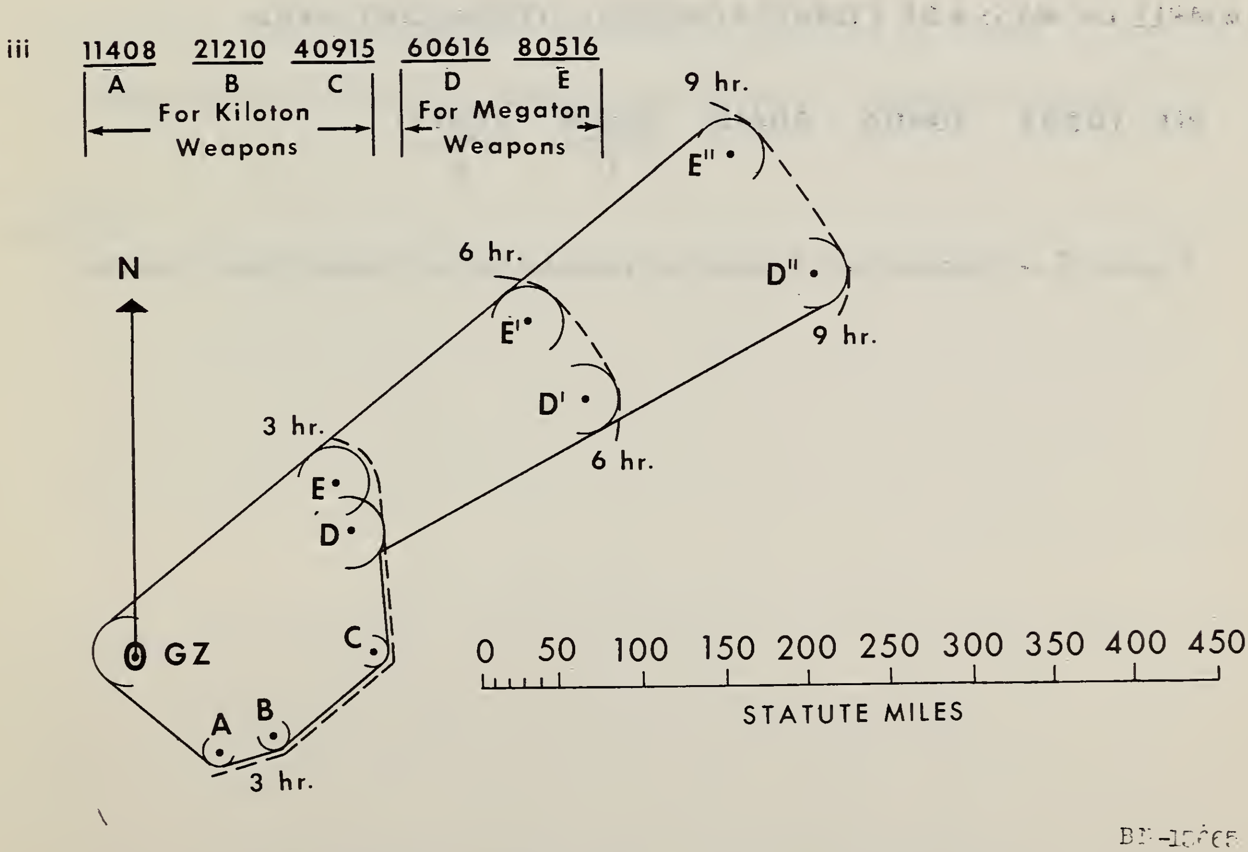
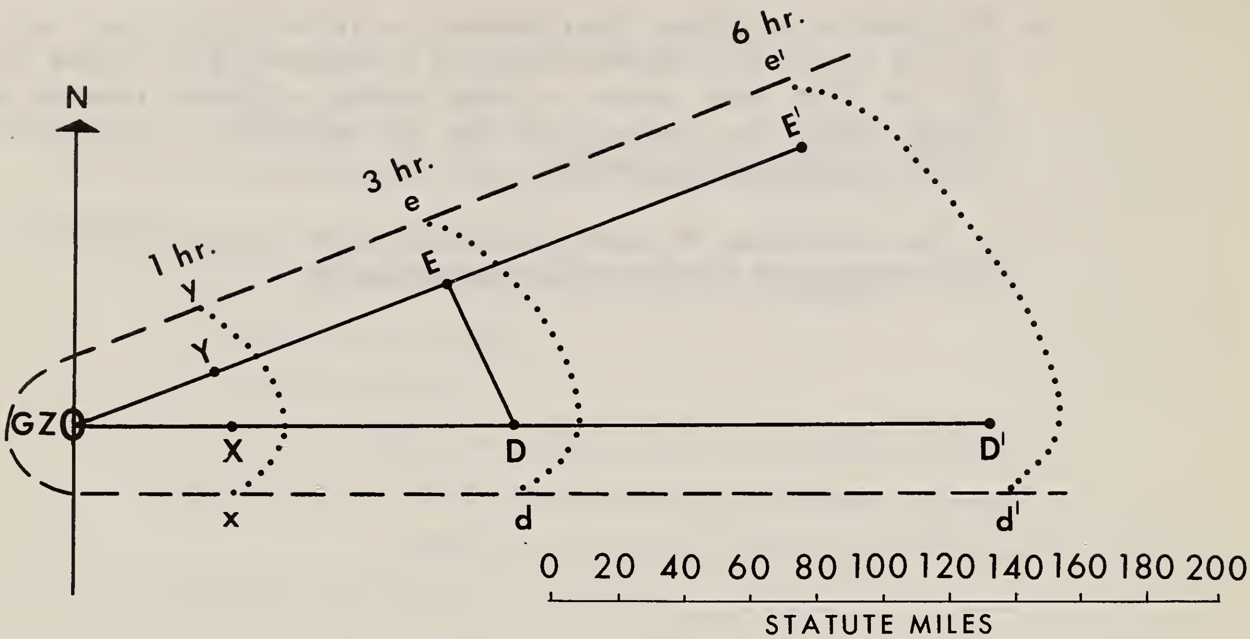


Figure 64.—Example of fallout plot using templates.

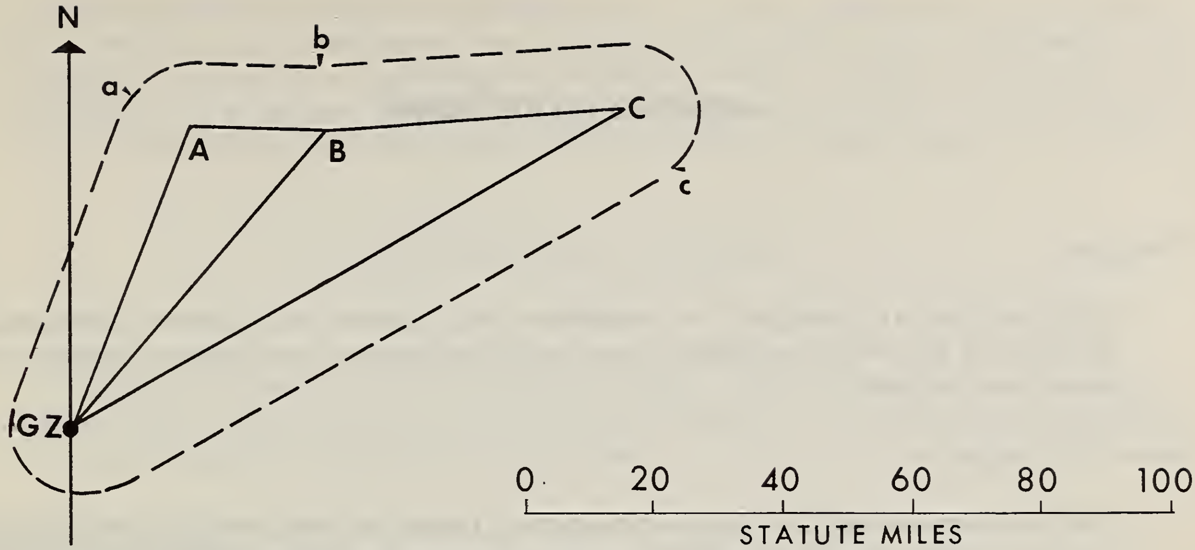


SAMPLE UF MESSAGE CORRESPONDING TO FALLOUT AREA

PIT 10205 20406 40610 $\underbrace{60914}_{D}$ $\underbrace{80712}_{E}$

BN-13666

Figure 65.—Construction of predicted fallout area for megaton-size weapons.



SAMPLE UF MESSAGE CORRESPONDING TO FALLOUT AREA

PIT	10205	20406	40610	60914	80712
	A	B	C		

FOR KILOTON YIELDS

BN-13668

Figure 66.—Construction of predicted fallout area for kiloton-size weapons.

MONITORING EXERCISE

Purpose

The exercise is designed to introduce the trainee to radiation fields and to familiarize him with elementary monitoring techniques, instrument response, and safety precautions.

Materials Required

One ion chamber and one Geiger counter are issued to each team of two trainees. The instructor needs cobalt 60 sources, source handling tongs, and radiation warning signs. Dosimeters should be worn during this exercise by the instructor and at least one of the trainees.

Location

A garden, porch, or similar area might be used for an outdoor exercise, or several rooms and a hall, or one large room may be used indoors.

Procedure

The sources are concealed so as to be out of sight of the student, but so chosen that the areas of significant readings will be in view of an instructor at all times.

The trainees should make a rought sketch of the area so that the location of the sources, when found, may be identified. The number of sources hidden will depend on the size of the area and the time allowed, and will be at the discretion of the instructor. A number of the small sources may be grouped together so as to produce a higher field of radiation. Trainees equipped with Geiger counters and ion chambers may experience the necessity for both instruments, some locations giving such intensities of radiation as to require that the Geiger counter be turned off.

The trainees should be directed to start the search in an orderly manner. Proceed in a general direction while observing the Geiger counter for signs of radiation. The right-angle approach should be used. Continue in one general direction until the point of highest reading is found, then go at right angles until the point of highest reading is again located (if the reading should decrease on the first right-angle attempt, reverse the direction of search) and continue in this manner until the source is located. The Geiger counter should be turned off when it no longer will read on-scale on the highest range and the ion chamber used to locate the source. Trainees should record the location of the source and

take a reading at approximately 2 feet and 4 feet away. Trainees should continue looking for other sources as time allows.

Attention should be called to the observance of safety precautions, the necessity for watching the instrument, the purpose of the film badge or dosimeter, the inability to gain any knowledge of radiation without suitable instruments, the difference of response between Geiger counter and ion chamber, and the application of the inverse square law in relation to these "point" sources.

RADIATION FIELD EXERCISE

Purpose

To familiarize trainees with the Geiger counter and ion chamber survey instruments, give them experience in evaluating readings, and allow them to observe the applicability of the inverse square law.

Materials Required

One Geiger counter and one ion chamber for each two trainees. Cobalt 60 source, source-handling tongs, and radiation warning signs. Device for holding exposed source. Film badges or dosimeters and charger. Yard stick or measuring tape.

Procedure

Place the cobalt 60 source in the center of selected location and mark lines radiating out from the source, with appropriate distances marked on the lines.

Check instruments for operability, and then take and record readings with both Geiger counter and ion chamber at 1, 2, 4, 8, and 16 feet from the source. Point out applicability of inverse square law.

If the radiation source being used is of such magnitude that the distances are not practical, the instructor should determine appropriate reading points.

Place instruments on lowest scale and note the maximum distance at which the radiation from <u>this</u> source can be detected.

DOSE AND DOSE RATE EXERCISE

Purpose

To demonstrate the related concepts of dose and dose rate.

Materials Required

CD V-786 Source Kit, source-handling tongs, radiation warning signs. Set of four to six dosimeters (0-200 mr), dosimeter chargers, clock.

Location

This exercise requires only a small area but consideration must be given to the fairly high levels of radiation in the vicinity.

Procedure

Dosimeter operation and performance are described and the four to six dosimeters to be used in the exercise are charged. The trainees may be allowed to charge the dosimeters if sufficient chargers are available.

The source inner container should be placed on its side and the top removed. This will give a high-intensity directional beam. The container should be placed so as to give considerable protection to personnel. Several locations (as many as the dosimeters being used) should have been marked on the floor with chalk or in some similar fashion. The trainees may place a dosimeter on each mark and record the time of the beginning of the exposure. If the dosimeters are placed approximately 3-1/2 feet from source, an exposure of 6 minutes will give an appreciable reading. At the end of the exposure period each dosimeter will be removed and the reading and duration of the exposure recorded. This dosage multiplied by ten will give the dosage equal to 1 hour of exposure.

A Geiger counter is then placed on each mark and the reading on the instrument recorded. The meter should be read from a position behind the container in order to keep out of the high-intensity beam.

The dose rate obtained from the survey meter should compare favorably with that obtained from the dosimeter after correction to its equivalent 1-hour exposure.

In addition to discussion of the object of the exercise, the variations in the rates so obtained may lead to an awareness and discussion of the critical nature of the geometry of such measurements.

Dosimeter charged ______________ (check only)

Time for dose to accumulate ______________

Dosimeter reading after exposure ______________

Dosimeter reading before exposure ______________

Dose indicated by dosimeter ______________

Rate of field by calculation ______________

Rate of field by G/M counter ______________

Materials

CD V-700 with speaker (may adapt to movie projector speaker) or Model 1613A - Classmaster (Nuclear Corporation) (a visible-audio counter).

P-32 (10 microcuries as liquid). May be obtained* from:

Atomic Corporation of America, 14725 Arminta St., Pomorama City 61, Calif.
Nuclear Chicago Corp., 333 E. Howard Ave., Des Plaines, Ill.; 8226 Fenton St., Silver Spring, Md.
Tracerlab, Inc., 1601 Trapelo Rd., Waltham 54, Mass.; 2419 South Blvd., Houston, Tex.

4 - 4 oz. ointment tins	3 polyethylene bags	Salt
Ash tray	Matches	2 apples
2 eyedroppers	3 paper towels	3 bananas
Wax pencil	2 large sheets of wax paper	1 orange
Methyl alcohol	2 sacks	Canned orange juice
1 paper cup		

Before class

1. Insert banana in cobalt 60 source container.

2. Contaminate - polyethylene bag containing fruit
   banana
   apple
   orange
   top of orange juice can

3. Salt in ointment tins to mark (line tins with polyethylene to permit reuse.) Contaminate surface of salt with P-32 using eyedropper. Monitor as you contaminate and bring activity to:

   1 can - 10-day level
   1 can - 30-day level
   1 can - above level
   1 can - nothing

Demonstrations:

1. Cannot destroy radioactivity - burn contaminated tissue with aid of methyl alcohol and show that contamination remains.

* Mention of companies or products in this paper does not imply recommendation or endorsement by the U. S. Department of Agriculture over others not mentioned.

2. Take fruit out of contaminated bag - show to be uncontaminated and eat.

3. Cut off contaminated portion of apple and eat remainder.

4. Decontaminate top of orange joice can - show no activity - open can - show juice free - drink.

5. Peel contaminated banana - show free of contamination - eat.

6. Peel contaminated apple - show free of contamination - eat.

7. Peel contaminated orange - show free of contamination - eat.

8. Explain P-32 Beta emitter - show does not go through source jar.

9. Bring over cobalt 60 source container. Explain gamma source - show activity goes through 3-inch lead container.

10. Remove banana from container - show free of contamination - peel and eat.

11. Explain food and water standards - explain why we have them - instrument to compare food in tin bottom with standard activity. Standards long half-life - measuring total activity. Good for first 30 days only - are actual limits and should not be exceeded. Ten day activity 200,000 dpm/cc, 1/3 for 30 days - always open shield. You are measuring both beta and gamma activity. Class mark 10-day and 30-day activity levels on face of instrument. Distance of probe from sample is important. Food samples must be well mixed and representative of lot. Plastic bags useful for shield covers in contaminated areas. Do not destroy nonperishable foods that exceed tolerances - permit decay.

    (See Appendix - Testing for Beta-Gamma Contamination with the Geiger-Mueller Counter, for use and capabilities of CD V-700.)

APPENDIX

Testing for Beta - Gamma Contamination with the Geiger - Mueller Counter

Studies with the ordinary Geiger-Mueller counter have shown that it can be used to determine beta-gamma activity in food and water supplies with certain standardized techniques. This is done with a Food and Water Standard (CD V-787) used as an emergency comparison standard. The Food and Water Standard contains sufficient uranyl acetate to give a response on a Geiger counter equal to that given by mixed fission products at the 10-day acceptable risk concentration. The prepared standard is in the lid of an ordinary 4-ounce ointment tin. The base is used to hold the sample being tested.

Fixing Reference Points on Geiger Scale

Place the ointment tin lid, containing the standard, on a level surface with the plastic face up. Turn on the Geiger-Mueller counter and set the range selector for the 0-20 or 0-50 mr/hr scale. Open the beta shield on the probe and place the probe diametrically across the lid, allowing it to rest on the edges of the lid with the exposed part of the tube facing the plastic. Watch the meter needle for 1 to 2 minutes and take the average reading. On many G-M instruments this reading will lie between 10 and 15 mr/hr. With a wax pencil mark on the glass face of the meter the value obtained. Divide the average reading obtained by 3, and place a similar mark at this value on the meter face.

The first mark on the scale given by the standard corresponds to a beta-gamma activity equal to that which may be tolerated in food and water that is to be consumed for not more than 10 days. For 30-day consumption, the beta-gamma activity is only one-third that which may be tolerated for 10 days. Hence, a reading between 9 and the next higher value shown by the pencil mark, when obtained on a sample of food or water, will indicate material which can be consumed for 30 days; a reading between the two wax pencil marks will permit a 10-day consumption; and anything reading beyond the highest mark will be unsafe for consumption without some treatment to reduce the level of activity.

A comparison standard prepared as indicated will not lose its radioactivity to any extent, the half-life of uranium-238 being approximately 4-1/2 billion years.

Testing for Food or Water

Place the base of the ointment tin on a level surface and fill it with the liquid or solid food material up to the lower edge of the indentation along the side. About 70 to 75 cc. of liquid will fill it to this point. The resulting head space in the container should be within about 1 mm. of the corresponding head space in the lid containing the standard. Again set the range switch to the 0-20 mr/hr (or 0-50 mr/hr) scale, open the beta shield, rest the probe on the edge of the tin, open side down and diametrically across the tin. The reading will indicate the permissible use of the food or water.

An important consideration in emergency measurements of radioactivity is to be sure that background counts are not interfering with the recorded values. After a nuclear attack, food or water samples may have to be removed from an area of high background or emergency shielding set up before adequate emergency measurements can be made. Another consideration is to keep the counter, particularly the probe, free from contamination with radioactive dust. Each use of the ointment tin base requires complete cleaning to prevent cross contamination. A suggested method is to use a paper or plastic liner within the ointment tin base, being careful to fill it up only to the level indicated and to rest the probe on the rim of the tin as described above. The used liner may then be thrown away. For routine field use, the battery and meter unit can be wrapped in a pliofilm bag, drawn together around the probe and earphone cables. The probe itself may be shielded from dust and contamination by a separate thin pliofilm or rubber bag.

Testing for Alpha Contamination

At the present no satisfactory method of testing for alpha contamination of food or water has been developed for use in the field. A laboratory, either stationary or mobile, could be readily equipped to make such analysis and judge the acceptability of samples, however.

TRAINING PROGRAMS

One-Day

Object

To teach the use of radiological monitoring instruments. To acquaint the trainees with the effects and hazards of radioactive fallout and the means of protecting against these hazards.

This is a suggested one-day course for training monitors in agriculture. It has been designed to include subject matter suitable for a briefing on monitoring and radiological defense in agriculture.

8:30	USDA's Monitoring Program
9:00	Film - A is for Atom
9:20	Radiological Defense
10:00	Break
10:15	Effects of Radiation on Livestock
11:00	Radiological Instrument Familiarization
11:30	Film - Fallout and Agriculture
12:00	Lunch
1:00	Decontamination of Food (Demonstration)
2:00	Remedial Measures for Agriculture
2:45	Break
3:00	Dose and Dose Rate Problems
4:00	Plotting Fallout (Domonstration)

Two and One-half Days

Object

To acquaint trainees with the effects of radioactive fallout on agriculture and the means by which these effects can be minimized.

Instruction should include basic physics of radiation, effects of ionizing radiations, physical effects of nuclear weapons, operation and use of radiological monitoring instruments, personnel protection, and techniques and limitations of decontamination.

This suggested two and one-half days course has been found to provide the minimum information essential for an understanding of radiological defense.

First Day

8:00	USDA's Monitoring Program and Responsibilities
8:30	Basic Concepts of Nuclear Science
9:55	Film - A is for Atom
10:15	Break
10:30	Instrument Familiarization
11:15	Biological Effects of Radiation
12:00	Lunch
1:00	Film - Fallout and Agriculture
1:30	Remedial Measures in Agriculture
2:15	Break
2:30	Survey Area (Exercise)
3:30	Film - Fundamentals of Radioactivity
4:00	Questions and Discussion

Second Day

8:00	Nuclear Weapons and Radiological Defense
9:10	Film - Basic Physics of an A Bomb
9:30	Personnel Protection
10:00	Break
10:15	Allowable Radiation Exposure
11:00	Dose and Dose-Rate Calculations
12:00	Lunch

Second Day (Cont'd)

1:00	Emergency Use of Food and Water (Demonstration)
2:00	Instrument Care and Use
2:45	Break
3:00	Plotting Fallout
4:15	Examination

Third Day

8:00	Questions and Discussions
8:45	Interaction of Radiation with Matter
9:45	Salvage and Decontamination (Techniques and Limitations)
10:15	Break
10:30	Film - Mission Fallout
11:00	Fallout on Soils, Water, and Plants

Five Days

Object

To train instructors in radiological monitoring. This course provides information on the effects of radiation, the problems associated with radiation, radioactive materials and radioactive fallout, the means of detecting the intensities of fallout, protective measures and available means to minimize radiation hazards and their effects.

The completion of this course by a trainee with a previous scientific background should qualify him for a license to handle radioactive material.

First Day

8:30	Introduction - Department's Monitoring Program and Responsibilities
9:15	Post-Attack Fallout Problems and Radiological Defense Programs
10:00	Break
10:15	Basic Physics of Radiation
11:30	Film - A is for Atom
12:00	Lunch
1:00	Film - Fallout and Agriculture
1:30	Remedial Measures For Agriculture

First Day (Cont'd)

2:00	Instrument Familiarization (Instrument Calibration)
3:30	Break
3:45	Film - Introduction to Radiation Detection Instruments
4:15	Personnel Protection

Second Day

8:30	Interaction of Radiation with Matter
10:00	Break
10:30	Film - Fundamentals of Radioactivity
11:30	Lunch
1:00	Survey Exercise Monitoring Protective Principles
3:00	Break
3:30	Monitoring Systems, Operations, and Communications
4:15	Questions and Discussion

Third Day

8:30	Nuclear Weapons
9:30	Break
10:00	Film - Basic Physics of an A Bomb
10:30	Exercise - Operation of Instruments in Radioactive Field
12:00	Lunch
1:00	Allowable Emergency Exposures
1:45	Dose and Dose Rate Calculations
2:45	Break
3:15	Handling Radioactive Material
4:00	Dose and Dose Rate Problems

Fourth Day

8:30	Biological Effects of Radiation
9:30	Break
10:00	Film - Mission Fallout

Fourth Day (Cont'd)

11:00	Denial Times
11:30	Lunch
1:00	Demonstration - Emergency Use of Food and Water
2:00	Fallout on Soils, Water, and Plants (Deposition and Migration)
3:00	Break
3:30	Probable Dosages in Various Foods Raised on Contaminated Land
4:30	Quiz

Fifth Day

8:30	Questions and Discussion
9:30	Break
10:00	Remedial Measures for Soil, Water, and Plants
11:00	Salvage and Decontamination of Foods
11:30	Lunch
1:00	Plotting Fallout
2:00	Instruction Methods
3:00	Department's Radiological Safety Program

VISUAL AIDS

A number of films have been used and found to be extremely helpful in the conduct of training courses in radiological defense. The suggested agenda for the various training courses indicate the subject films recommended for use. These agenda are found on pages 222 to 226.

Films

The films listed below are available for use on loan from the sources indicated:

A is for Atom (Sources A, B, and C)

An animated cartoon-film explaining atomic structure, nuclear fission, and the peacetime applications of the atom. (15 min., 16 mm., color, sound).

Atomic Physics (Source B)

A study of the history and development of atomic energy, stressing nuclear physics. Dalton's basic atomic theory; Faraday's early experiments in

electrolysis; Mendeleeff's periodic table; early concepts and size of atoms and molecules. Demonstrates how cathode rays were investigated and electron discovered; how nature of positive rays was established; how X-rays were found and put to use. Presents research tools of nuclear physics. Explains work of Joliot, Curies, and Chadwick in discovery of neutron. Splitting of lithium atom by Cockcroft and Walton. Einstein tells how their work illustrates his theory of equivalence of mass and energy. Explains uranium fission. Why possible to make A-bomb. (90 min., 16 mm., black and white, sound).

Basic Physics of an A Bomb (Sources A and B)

The film discusses the principles of the atomic bomb and tells how it was developed. (18 min., 16 mm., color, sound.)

Fundamentals of Radioactivity (Sources A, B, and D)

Traces uranium from prospector to the Atomic Energy Commission. Shows how uranium changes into other elements through radioactive decay and through nuclear fission. Mention made of Einstein's equation $E = mc^2$, the atomic bomb, and use of nuclear power for industry. Stable and radioactive isotopes are explained, with isotope charts and energy level diagrams used to illustrate decay. Various radiations resulting from nuclear changes are described in detail. The nuclear reactor is described in terms of fission and moderation. Target materials introduced into a typical nuclear reactor and withdrawn as radioisotopes, and the processing of fission products, are shown. More than fifty terms and concepts are defined and explained. (59 min., 16 mm., black and white, sound.)

Introduction to Radiation Detection Instruments (Sources A and B)

This film discusses the various radiological detection instruments, including dosimeters and monitoring devices, their operating principles, and uses. (19 min., 16 mm., black and white, sound.)

Medical Aspects of Nuclear Radiation (Sources A and B)

This film discusses the biological effects of nuclear radiation and the principles of protecting against the related hazards. (50 min., 16 mm., color, sound.)

Mission Fallout (Source E)

This picture was shot at the Nevada Test Site during the 1957 Operation Plumbbob series. It describes in detail the training program for ground and aerial radiological defense monitors which was conducted as a part of the test program. The film was made to show personnel of the radiological defense program the procedures used in monitoring and plotting actual fallout within the test site. The film reviews the nature of radioactivity and the characteristics of fallout. It also describes OCDM radiation measuring instruments and calibration procedures used to assure their accuracy. (45 min., 16 mm., color, sound.)

Fallout and Agriculture (Source B*)

This film was prepared to provide information on radioactive fallout and its movement through the atmosphere resulting in the exposure of man and his animals to radiation and the contamination of agricultural resources. It discusses the radioactive elements that are of concern to agriculture and can contaminate our crops and food supplies. Means of protecting against radiation and minimizing the contamination of soil, crops, and other foods are discussed and illustrated. The film should be useful and interesting in discussing the problem of radioactive fallout and its effects on the farm.

The film can be used for training and informational purposes for agricultural groups and officials, as well as civic organizations. It is suitable for showing to any adult group, urban or suburban, as well as the rural audience at which it is aimed. Cleared for television use. (23 min., 16 mm., sound, color.)

*This film has been distributed to the cooperating film libraries of all State agricultural colleges.

Rural Community Defense

This film shows that farm families can plan now for survival by developing community survival plans and by preparing to meet emergencies. Cleared for television use. (13-1/2 min., 16 mm., sound, black and white.)

Note: This film is available from the cooperating film libraries of all State agricultural colleges.

The Petrified River (Source B)

The film tells how uranium was deposited far back in geologic time; about the search for this precious metal on the Colorado Plateau, and how it is mined and milled; and about the peacetime applications of the atom's energy for power and to produce radioactive isotopes for medical diagnosis and therapy, agriculture, industry, and basic research. (28 min., 16 mm., sound, color.)

Sources

Source A - Cooperating Film Libraries

Georgia - Georgia Agricultural Extension Service, Athens.

Iowa - Visual Instruction Service, Iowa State University, Ames.

Minnesota - Extension Service, Institute of Agriculture, University of Minnesota, St. Paul 1.

Montana - Extension Service, Montana State College, Bozeman.

Nevada - Extension Service, University of Nevada, Reno.

New Jersey - New Jersey State Museum, State House Annex, Trenton 7.

New York - Film Library, New York State Department of Commerce, Albany 7.

Oregon - Department of Visual Instruction, Oregon State College, Corvallis.

Texas - Extension Service, Texas A. & M. College, College Station.

West Virginia - Audio-Visual Aids Department, The Library, West Virginia University, Morgantown.

Source B

Motion Picture Service, U. S. Department of Agriculture, Washington 25, D. C.

Source C - AEC Film Libraries

Canada, Maine, New Hampshire, Vermont, Massachusetts, Connecticut, Rhode Island, Pennsylvania, New Jersey, or New York

Director, Public Information Service, U. S. Atomic Energy Commission, New York Operations Office, 70 Columbus Avenue, New York 23, N. Y.

Delaware, Maryland, Virginia, West Virginia, or the District of Columbia

Elton P. Lord, Public Information Service (Pictorial), U. S. Atomic Energy Commission, Washington 25, D. C.

Mississippi, Alabama, Florida, North Carolina, South Carolina, or Georgia

Assistant to the Manager for Public Education, U. S. Atomic Energy Commission, Savannah River Operations Office, P. O. Box A, Aiken, S. C.

Indiana, Ohio, or Michigan

Motion Picture Film Library, U. S. Atomic Energy Commission, Portsmouth Area Office, P. O. Box 268, Portsmouth, Ohio.

Montana, Utah, or Idaho

Assistant to the Manager for Information, U. S. Atomic Energy Commission, Idaho Operations Office, P.O. Box 1221, Idaho Falls, Idaho.

California or Hawaii

Assistant to the Manager, U. S. Atomic Energy Commission, San Francisco Operations Office, 518 - 17th Street, Oakland 12, Calif.

Colorado, Wyoming, Kansas, or Nebraska

Director, Information Division, U. S. Atomic Energy Commission, Grand Junction Operations Office, Grand Junction, Colo.

North Dakota, South Dakota, Missouri, Iowa, Minnesota, Wisconsin, or Illinois

Information Assistant to the Manager, U. S. Atomic Energy Commission, Chicago Operations Office, P.O. Box 59, Lemont, Ill.

Kentucky, Mississippi, Arkansas, Louisiana, or Tennessee

Public Information Officer, U. S. Atomic Energy Commission, Oak Ridge Operations Office, P.O. Box E, Oak Ridge, Tenn.

Nevada, Arizona, New Mexico, Texas, or Oklahoma

Director of Information, U. S. Atomic Energy Commission, Albuquerque Operations Office, P.O. Box 5400, Albuquerque, N. Mex.

Washington (State), Oregon, or Alaska

Director, Information Division, U. S. Atomic Energy Commission, Hanford Operations Office, P.O. Box 550, Richland, Wash.

Source D (order from the nearest library)

Commanding General, First Army, Governor's Island, New York 4, N.Y. (Attn: Central Film Exchange)

Commanding General, Second Army, Ft. George Meade, Md. (Attn: Central Film Exchange)

Commanding General, Third Army, Ft. McPherson, Atlanta, Ga. (Attn: Central Film Exchange)

Commanding General, Fourth Army, Ft. Sam Houston, San Antonio, Tex. (Attn: Central Film Exchange)

Commanding General, Fifth Army, Ft. Sheridan, Chicago, Ill. (Attn: Central Film Exchange)

Commanding General, Sixth Army, Presidio of San Francisco, San Francisco, Calif. (Attn: Central Film Exchange)

Commanding General, Military District of Washington, Washington 25, D. C. (Attn: Central Film Exchange)

Medical Illustration Service, Armed Forces Institute of Pathology, Walter Reed Medical Center, Washington 25, D. C.

Source E - Office of Civil and Defense Mobilization

Region 1 - Director, OCDM Region 1, Oak Hill Road, Harvard, Mass.

Region 2 - Director, OCDM Region 2, Olney, Md.

Region 3 - Director, OCDM Region 3, P.O. Box 108, Thomasville, Ga.

Region 4 - Director, OCDM Region 4, Battle Creek, Mich.

Region 5 - Director, OCDM Region 5, P.O. Box 2935, University Hill Station, Denton, Tex.

Region 6 - Director, OCDM Region 6, Denver Federal Center, Building 50, Denver 25, Colo.

Region 7 - Director, OCDM Region 7, Naval Auxiliary Air Station, Santa Rosa, Calif.

Region 8 - Director, OCDM Region 8, Everett, Wash.

Slides

Biological Effects of Radiation on Livestock
Biomedical Aspects
Fallout and OCDM's Radiological Defense Program
Fallout on Agriculture
Fallout Patterns
Formation, Distribution, and Dispersal of Radioactive Fallout
Medical Aspects
Pathology of Radiation on Livestock
Radiation Measuring Devices
Radioactive Decay
Radiological Defense
Soil Decontamination
Targets

Note: Sets of 2x2 slides on the above subjects have been made available in limited quantities to:

Agricultural Marketing Service
Agricultural Research Service
  Animal Disease Eradication Division
  Meat Inspection Division
Forest Service - Regional Offices
Soil Conservation Service - Information Centers

Publications

ARS Special Report 22-55 - Radioactive Fallout in Time of Emergency, Effects Upon Agriculture. A semi-technical publication for professional and technical agricultural scientists and officials.

USDA Farmers' Bulletin No. 2107 - Defense Against Radioactive Fallout on the Farm. Revised April 1961.

USDA Radiological Monitoring Program. This is a manual on the Department's Radiological Monitoring Program that should be useful to the regulatory forces with monitoring responsibility. May 1961.

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Growth Through Agricultural Progress